(12) LEVEL III

AD-E430594

B.S

AD

AD A098036

MEMORANDUM REPORT ARBRL-MR-03072

(Supersedes IMR No. 679)

AEROBALLISTIC TESTING OF THE XM825 PROJECTILE: PHASE II

W. P. D'Amico
V. Oskay

January 1981

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

Approved for public release; distribution unlimited.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER MEMORANDUM REPORT ARBRL-MR-03072 ✓	2. GOVT ACCESSION NO. AD-A09	3. RECIPIENT'S CATALOG NUMBER 8036
4. TITLE (and Subtitle) AEROBALLISTIC TESTING OF THE XM825 PROJECTILE: PHASE II		5. TYPE OF REPORT & PERIOD COVERED Final
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) W.P. D'Amico V. Oskay		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS US Army Ballistic Research Laboratory ATTN: DRDAR-BLL Aberdeen Proving Ground, MD 21005		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 1W663608DE82
11. CONTROLLING OFFICE NAME AND ADDRESS US Army Armament Research & Development Command US Army Ballistic Research Laboratory ATTN: DRDAR-BL Aberdeen Proving Ground, MD 21005		12. REPORT DATE JANUARY 1981
		13. NUMBER OF PAGES 50
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

This report supersedes IMR No. 679 dated March 1980.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

White Phosphorous
Improved Smoke Munition
Projectile Stability

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

During the week of 10 December 1979 yawsonde-instrumented XM825 projectiles were flight tested at Dugway Proving Ground, Utah. The XM825 projectile carries a single canister that contains rigid felt wedges and white phosphorous (WP). All projectiles were conditioned to 63°C so that the WP would be in a liquid state. Two types of felt wedges were evaluated. One type of payload contained F7 felt wedges, which had previously been flight tested, while a second payload contained denser F3 felt wedges. Neither type payload showed any flight instability for supersonic launch conditions (Zones 6 and 8). At Zone 4 for

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. ABSTRACT (continued)

induced yaw levels of 8 degrees, the F3 payloads were stable while the F7 payloads were unstable.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (continued)

I. INTRODUCTION

The XM825 projectile carries a single canister loaded with rigid felt wedges and white phosphorous (WP). Previous aeroballistic testing with the WP in a liquid state indicated flight instabilities for yaw levels larger than 9 degrees at Charge 4.[1] Intuitively, if the density of the felt wedges were increased, then the destabilizing effects of the liquid/fiber payload could be reduced. During the week of 10 December 1979 at Dugway Proving Ground (DPG), Utah, XM825 projectiles with felt wedges of two different densities were tested. For similar launch disturbances, yawsonde data showed the higher density felt payloads were stable, while the less dense felt payloads were unstable. Table 1 (see page 16) provides a round-by-round summary of the test program. Figure 1 gives a cut-away view of the XM825 projectile, including a burster cup located in the ogive, x-ribs within the payload canister, and several felt wedges. The XM825 has the exterior shape of the M483A1 projectile.

II. BACKGROUND

White phosphorous is carried on-board projectiles for use as a screening agent, but suffers the disadvantage of a low melting point, 44.1°C. It is well known that projectiles with liquid payloads can suffer flight instabilities, so new payload concepts that employ WP must be tested when the WP is in a liquid state. WP-payload concepts that deploy point sources for smoke production are now under development. An initial concept employed a WP-saturated cotton wick, but when the WP was in a liquid state dramatic flight instabilities occurred for transonic and supersonic launch conditions.[2 3 4 5]

---

1. *W.P. D'Amico, Jr., "Aeroballistic Testing of the XM825 Projectile: Phase I," Ballistic Research Laboratory Memorandum Report ARBRL-MR-02911, March 1979. AD# B037680L.*

2. *W.P. D'Amico, Jr., "Early Flight Experiences with the XM761," Ballistic Research Laboratory Memorandum Report ARBRL-MR-2791, September 1977. AD# B024975L.*

3. *W.P. D'Amico, Jr., "Field Tests of the XM761: First Diagnostic Test," Ballistic Research Laboratory Memorandum Report No. 27[illegible], September 1977. AD #B024976L.*

4. *W.P. D'Amico, "Field Tests of the XM761: Second Diagnostic Test," Ballistic Research Laboratory Memorandum Report ARBRL-MR-0[illegible], January 1978. AD #B025305L.*

5. *W.P. D'Amico, W.H. Clay, and A. Mark, "Diagnostic Tests for Wick-Type Payloads and High Viscosity Liquids," Ballistic Research Laboratory Memorandum Report ARBRL-MR-02913, April 1979. AD# A072812.*

A laboratory spin fixture was constructed by the Armaments Concepts Office/Edgewood Area that allowed various payload concepts to be screened prior to flight testing.[6] This fixture measures the despin history of a payload canister from a 155mm projectile when it is forced to precess at a constant angle from the vertical. The spin history together with the spin moment of inertia of the spinning parts can be used to compute an effective despin moment. For the ill-fated wick payload despin moments thirty times greater than the aerodynamic despin moment were observed for a Charge 6 launch condition. The spin fixture was also used to investigate the despin moment of felt wedge/liquid payloads. The despin moments measured for the prototype felt wedge payloads were substantially lower than those previously measured for the wick payloads. These data provided the impetus for flight testing a felt wedge/WP concept that evolved into the XM825 projectile.[7] Although the stability of the XM825 was deemed to be adequate within Reference 1, variations of the felt wedge payload were investigated on the spin fixture in an effort to increase the stability of the projectile.

Table 2 (see page 17) provides a listing of some of the properties of wool felt important for WP payloads. First, the felt must have sufficient tensile strength to withstand launch accelerations and ejection from a canister. Second, it must be highly absorbent, i.e., it should suspend a large quantity of WP so as to produce a good point source for smoke. Third, a higher density felt should reduce any liquid/fiber destabilizing effects. The initial XM825 payload utilized an F7 felt, but despin moments for F3 felt wedges were substantially smaller. Hence, F3 felt payloads were constructed and flight tested.

---

6. *Miles C. Miller, "Flight Instability Test Fixture for Non-Rigid Payloads," Chemical Systems Laboratory Special Publication No. ARCSL-SP-79005, January 1979. AD# A030-430.*

7. *W.P. D'Amico and W.H. Clay, "Flight Tests for Prototype Felt Wedge/White Phosphorous Improved Smoke Concept," Ballistic Research Laboratory Memorandum Report ARBRL-MR-02824, April 1978. AD #A054643.*

III. TEST RESULTS

A. Projectile Hardware

The projectile hardware, called B and C types for this test, was identical to that tested in the March 1978 series reported in Reference 1. The only difference between the B and C type projectile was the utilization of F7 or F3 felts, respectively. The B type projectile carried 120 wedges with approximately 6.2 kg of WP, while the C type projectile carried 108 wedges with 5.8 kg of WP. The center of gravity of the payload canister and the projectile body are very close, and no appreciable center of gravity difference existed between the B and C type shell. The projectile developers do not consider the slight reduction in WP of the C projectiles to degrade the terminal effects.* The hardware tested in March 1978 (Reference 1) carried fewer wedges (only 92) than the B type shell.

B. Instrumentation

All projectiles were instrumented with fuze-configured BRL yawsondes.[8] The M198 and M109A1 weapons, a muzzle chronograph, a time zero system, and the ground receiving station were operated by DPG personnel. Yaw induction for the Charge 4 launches from the M109A1 was accomplished by a modified muzzle brake with 12.7cm side plates. This brake was one of the yaw inducers used in the March 1978 tests. Also, a video camera was located behind the gun and visually tracked all projectiles to impact. In cases where yawsonde data were not obtained, camera data were used to categorize the flight of the projectile as stable or unstable.

C. Yawsonde Data

The quality of the yawsonde data is listed in Table 1, but further explanation is required. Data were not received from two rounds, DPG 661B and DPG 713C, and smear photographs indicated structural failure of the plastic windscreen of these yawsondes. Both of these projectiles were launched at Charge 8. The windshield of the BRL yawsonde has been modified to avoid such failures. DPG 659B had only one operable optical sensor, hence only spin data were obtained. Data were lost from DPG 662B because of a tape recorder malfunction during the count down sequence. Also, telemetry data did not produce usable results for DPG 666B and DPG 715C.

**Private communication with J. McGivrigan, Smoke Branch, Chemical Systems Laboratory.*

8. *W.H. Mermagen and W.H. Clay, "The Design of a Second Generation Yawsonde," Ballistic Research Laboratories Memorandum Report No. 2368, April 1974. AD# 780064.*

A short description of the format of yawsonde data follows. The data are provided in the form of the complementary solar angle (SIGMA N) and the spin (PHI DOT) as functions of time of flight. SIGMA N is the complement of the solar aspect angle, the angle between a vector drawn to the sun and the spin axis of the projectile. The local excursions of SIGMA N represent the yawing motion of the projectile about the trajectory. Spin data are actually in the form of the time-derivative of the Eulerian roll angle (PHI) of the projectile. Oscillations are normally present in PHI DOT data and are due to the yawing motion of the projectile. For large angular motion, Murphy has provided a method to compute PHI DOT correctly.[9] The first maximum angle (FMA) is defined as half of the first recorded peak-to-peak excursion of SIGMA N. FMA values provide an estimate of the first maximum yaw only if data are acquired soon after shot exit.

1. Firings of 12 December 1979

No usable data were recorded for DPG 666B, but video data indicated that the projectile flight was stable. DPG 658B was launched supersonically with a small FMA of approximately 1 deg (Figure 2). Small FMA levels are expected for supersonic launch conditions since the projectile is aeroballistically very stable. The yawing motion exhibited a limit cycle behavior typical of the M483A1 family during the later portions of the trajectory. Spin data are shown in Figure 3. The spin data for DPG 659B show no abnormal behavior (Figure 4). No yaw data are presented since only one optical sensor was operative. The solar angle data for DPG 660B are shown in Figure 5, while the spin data are shown in Figure 6. All of the data indicate a stable flight. No yawsonde data were received for DPG 661B, but video data showed a stable flight.

2. Firings of 13 December 1979

DPG 709C was launched with an FMA of 2 deg (Figure 7) and was stable. The spin data also were quite normal (Figure 8). The yawsonde data for DPG 710C and DPG 711C (Figures 9, 10, 11, and 12) were similar to the data for DPG 709C. The launch disturbance for DPG 712C was 2 deg, but that disturbance quickly damped as seen in Figure 13. The spin data for this round were also regular (Figure 14).

---

9. *C.H. Murphy, "Effect of Large High-Frequency Angular Motion of a Shell on the Analysis of Its Yawsonde Records," Ballistic Research Laboratories Memorandum Report No. 2581, February 1976. AD #B0094210.*

3. Firings of 14 December 1979

No yawsonde data were recorded for DPG 662B, but the video data indicated that the projectile was stable. DPG 714C was launched with an FMA of 8 deg and damped quickly to a stable motion typical for transonic and high subsonic flight, as shown in Figures 15a and 15b. Figure 16 provides the spin data. DPG 715C had no usable data, but again video data indicated a stable flight. DPG 663B did not produce clean data until 1.5 s into its flight, and even then the data transmission was not optimal. As such, no description of the launch disturbance can be made, but the data clearly show a violent flight instability similar to the type experienced in the March 1978 series (Figure 17). The spin data show a rapid decrease in spin at approximately 7.5 s, and this behavior is also typical of a liquid/projectile interaction. DPG 664B also exhibited violently unstable behavior. Figures 19a and 19b show the solar angle data with an FMA of approximately 9.5 deg. The spin data are shown in Figure 20 and show a rapid decrease in spin at 6 s.

IV. DISCUSSION

The ballistic testing in this program fell into two categories based upon launch velocities: supersonic and transonic. The supersonic tests were conducted to assure that flight instabilities late in the trajectory did not occur as with the XM761 WP/wick projectile.[4] None of the yawsonde data suggest stability problems at supersonic launch conditions for either the F3 or the F7 felts. The most critical test rounds were the yaw induced, transonic flights. Unfortunately, data were lost, but the evidence clearly indicates that the F3 felt wedge payloads were more stable than the F7 payloads. The largest disturbance induced at launch for an F3 felt projectile was only 8 deg.

Many projectile aeroballistic tests have been conducted at DPG, which has an elevation of approximately 1300m. Testing of two prototype red phosphorous projectiles from the M483A1 family, the XM803[10] and the XM802[11] resulted in yaw levels of 8 to 12 deg for stable shell. During all of these tests conducted at DPG, the same modified muzzle brake has been used. In the March 1978 series of tests for the XM825, yaw levels of approximately 8 deg were reached when the WP was in a solid state. Also, data from an unstable XM825 projectile tested in the March 1978

10. W.P. D'Amico, "XM803 Yawsonde Reduction," *Ballistic Research Laboratory Memorandum Report in publication.*

11. A. Mark and W.H. Clay, "Aeroballistic Test of the XM802 RP Smoke Projectile," *Ballistic Research Laboratory Memorandum Report ARBRL-MR-02877, November 1978. AD B033753L.*

series have been re-examined. One round, DPG 6, was fired near the edge of the test window where the calibration data for the yawsonde are nonlinear. Figure 21 gives the solar angle data for this round using a second order Newton interpolation of the calibration data (as was used for all of the data processed within this report). The FMA shown in Figure 21 is 10 deg instead of the 11 deg reported in Reference 1. The yaw levels of the December 1979 series were not large, but they were very similar to amplitudes previously obtained for shell of the M483A1 family at DPG.

It would be advisable to induce larger launch yaws than those obtained so as to determine the critical yaw angle for the XM825 at transonic launch conditions. The launch conditions appropriate to the aeroballistic testing of a projectile with a potentially destabilizing payload are unusual. For such projectiles, the aeroballistic damping along the trajectory should be minimized by testing under low atmospheric density conditions. For this condition, the yaw damping will not camouflage a payload instability. Projectile tests should also be conducted for large launch yaws, but there are many variables that determine the yawing motion of a projectile near the muzzle of a weapon. The angular motion of a symmetric missile can be described by the complex yaw[12],

$$\xi = K_1 e^{i\phi_1} + K_2 e^{i\phi_2} \quad . \tag{1a}$$

where

$$K_j = K_{j0}\, e^{\lambda_j s} \quad (j=1,2) \tag{1b}$$

$$\phi_j = \phi_{j0} + \phi_j' s \quad (j=1,2) \tag{1c}$$

Arc length along the trajectory is defined by s. The usual forms for the fast (j=1) and slow (j=2) precessional frequencies are

$$\phi_j' = (I_x \,/\, 2\, I_y)\,(pd/V)\,(1 \pm \sigma), \tag{2}$$

where

$$\sigma = (1 - 1/s_g)^{\frac{1}{2}}, \tag{3}$$

and

$$s_g = (pd/V)^2\,(I_x{}^2/2I_y S d^3)\,(1/\rho\, C_{M_\alpha}). \tag{4}$$

---

12. *C. H. Murphy, "Free Flight Motion of Symmetric Missiles," Ballistic Research Laboratory Report No. 1216, July 1963. AD# 442757.*

The initial modal amplitudes can be determined from the initial angle, $\hat{\xi}_o$ and the initial angular rate, $\hat{\xi}'_o$.

$$K_{10}e^{i\phi_{10}} = \frac{\tilde{\xi}'_o - (\lambda_2 + i\ \phi'_2)\ \tilde{\xi}_o}{\lambda_1 - \lambda_2 + i\ (\phi'_1 - \phi'_2)} \tag{5a}$$

and

$$K_{20}e^{i\phi_{20}} = \frac{\tilde{\xi}'_o - (\lambda_1 + i\ \phi'_1)\ \tilde{\xi}_o}{\lambda_2 - \lambda_1 + i\ (\phi'_2 - \phi'_1)} \quad . \tag{5b}$$

Using these expressions for K_{10} and K_{20}, several approximations can be made to determine the angular motion near the muzzle. First, since only the motion near the muzzle is of interest, damping will be neglected ($\lambda_1 = \lambda_2 \cong 0$). Second, assume that the projectile exits the gun with zero yaw ($\xi_o = 0$). If this were true, then K_1 and K_2 must be of equal magnitude but opposite phase. The assumption of $|K_1| = |K_2|$ near the muzzle is substantiated by the Sigma N histories in Figures 15b and 19b. The evaluation of K_{10} and K_{20} still depends upon $\tilde{\xi}'_o$, however. In practice the reproducibility of $\tilde{\xi}'_o$ in magnitude and phase is poor. For a constant $\tilde{\xi}'_o$, a relative scale factor, A_{mn}, can be formed by a ratio of K_{10} amplitudes for two different launch conditions. Since $K_1 \approx K_2$ near the muzzle, then A_{mn} also yields a scale factor for the total yaw. For $\lambda_1 = \lambda_2 = \tilde{\xi}_o = 0$ and $\phi'_1 - \phi'_2 = (I_x/I_y)\ (pd/V)\ \sigma$,

$$A_{mn} = \Big[(pd/V)\ (I_x/I_y)\sigma\Big]_m \Big/ \Big[(pd/V)\ (I_x/I_y)\sigma\Big]_n \tag{6}$$

Consider the case where the exterior shape and moments of inertia of the projectile are not design parameters and are held constant, then A_{mn} depends upon s_g - the gyroscope stability factor, pd/V - the twist of the projectile through the air, ρ - the atmospheric density, and C_{M_α} - the static moment coefficient. For the projectile tests of References 13 and 14, high density conditions were selected to reduce s_g.

A dilemma exists since large ρ increases both the launch yaw and the aeroballistic damping. One can attempt to maximize C_{M_α}, which is a strong function of the Mach number. This is often difficult, since nonstandard powder charges are required and local wind conditions may be variable. It may be more desirable to vary the twist of the gun to modify s_g. The twist, n, of the M109A1 system is 20 cal/rev, while the older M2 gun has a 25 cal/rev twist. The gun twist, $2\pi/n$, replaces pd/V leaving,

$$s_g = \left[2\pi^2 I_x{}^2/I_y \; Sd^3 \rho C_{M_\alpha} \right] \; (1/n)^2$$

Typical parameters for the XM825 at DPG with a transonic launch velocity are:

$$I_x = 0.1679 \text{ kg}\cdot\text{m}^2$$

$$I_y = 1.8263 \text{ kg}\cdot\text{m}^2$$

$$\rho = 1.046 \text{ kg/m}^3 \qquad (15^\circ\text{C nominal})$$

$$C_{M_\alpha} = 4.5$$

For these parameters,

$$s_g \; (n{=}20) = 2.29$$

and

$$s_g \; (n{=}25) = 1.47,$$

and

$$A_{mn} = 1.66$$

If the M2 gun were fitted with a yaw inducer that produced 8 deg of yaw then a yaw level of over 13 deg is possible. If large yaws are required for the XM825 at DPG, then a yaw inducer should be constructed for use with the M2 gun.

---

13. *J.H. Whiteside, "Flight Behavior Test of 155mm XM687E1 and XM718E1 and 8-Inch XM650E4, PXR6231, XM711, and XM736 Shell at Nicolet, Canada, During the Winter of 1975-1976," Ballistic Research Laboratory Memorandum Report No. 2732, March 1977. AD# B018149L.*

14. *V. Oskay and J.H. Whiteside, "1974-1975 Winter Tests of 155mm (M483 Family) and 8-Inch (M509 Family) High-Capacity Shell at Nicolet, Canada," Ballistic Research Laboratory Memorandum Report No. 2723, January 1977. AD# B017015L.*

Yawsonde data can also be processed to eliminate some of the bothersome signals produced by the measurement system. For example, the solar angle data can be digitally filtered in a band pass mode to yield the amplitude history of the fast precessional mode. Figure 22 shows the data from DPG 664B for a band pass of 2 to 15 Hz. Also, the spin can be digitally low pass filtered to remove the effects of the yaw on PHI DOT. Figure 23 shows data from DPG 664B that have been low pass filtered at 4 Hz. If it were assumed that the despin moment could be computed from these spin data, then first order comparisons with the spin fixture data of Miller[6] could be made. If the data in the first 4 s are used to estimate the effects of air friction on the projectile, then subsequent data can be used to calculate a spin derivative due to only the liquid payload. This derivative when combined with the axial moment of inertia of the rigid parts of the XM825 (I_x = 0.1679 kg·m^2) produced a despin moment of approximately 24 N·m (or 17.7 ft·lbf). From Figure 22 at 6 s, the projectile had a fast precessional amplitude of approximately 40 deg. This amplitude is much larger than can be generated by the spin fixture. Most data from the spin fixture are at a coning angle of 20 deg, which from Figure 22 occurred at approximately 5 s. At this time frame, the despin moment was much smaller with a magnitude of 4.2 N·m (or 3.1 ft·lbf). This value is approximately three times larger than that predicted by the spin fixture (see Figure 25 of Reference 1).

V. CONCLUSIONS

Yawsonde-instrumented XM825 projectiles were tested with felt wedges of higher than standard density. This single modification appears to have increased the aeroballistic stability of the projectile when the WP is in a liquid state. Yaw-induced projectiles at Charge 4 were stable when the payloads contained the higher density felt, while the standard density felt payloads were unstable for similar launch disturbances. The maximum launch yaw achieved for stable flights was 8 deg. If higher launch levels are desired, tests must be conducted at a site other than Dugway Proving Ground or a novel and controllable technique for yaw induction must be used. It would be desirable to determine the upper bounds of yaw for stable flight performance for the higher density felt wedge payload, and the use of the M2 gun system with a lower twist tube appears to be a viable option.

TABLE 1. ROUND-BY-ROUND DATA[1]

FIRED ON 12 DECEMBER 1979 FROM AN M198

DPG Number[2]	BRL Number	Muzzle Velocity(m/s)	Launch Time(Zulu)	Comments
666B	1450	469.0	17:39	Stable,unusable data
658B	1453	471.0	17:49	Stable, good data
659B	1618	471.5	18:00	Stable, spin data only
660B	1456	816.8	18:23	Stable, good data
661B	1457	816.7	18:32	Stable, no transmission
FIRED ON 13 DECEMBER 1979 FROM AN M198				
709C	1458	468.7	16:54	Stable, good data
710C	1459	472.8	17:09	Stable, good data
711C	1559	468.2	17:16	Stable, good data
712C	1566	807.5	17:22	Stable, good data
713C	1580	806.5	17:29	Stable, no transmission
FIRED ON 14 DECEMBER 1979 FROM AN M109A1[3]				
662B	1553	331.9	17:01	Unstable, tape recorder failure
714C	1554	332.1	17:27	Stable, good data
715C	1555	333.7	17:34	Stable, unusable data
663B	1556	333.7	17:42	Unstable, good data
664B	1565	335.0	17:51	Unstable, good data

1. *All rounds were launched at a quadrant elevation of 533 mils and were conditioned to 63°C.*

2. *A suffix B identifies F7 felt wedge payloads, while C identifies F3 felt wedge payloads.*

3. *All rounds in this series were launched with artificial yaw induction by a modified muzzle brake.*

TABLE 2. PROPERTIES OF INDUSTRIAL WOOL FELTS*

Society of Automotive Engineers (SAE) Specification Number	Specific Gravity	Liquid Absorption (% by volume)	Minimum Tensile Strength (psi)
F1	0.384	71	600
F2	0.342	74	500
F3	0.342	74	500
F4	0.330	76	400
F5	0.330	75	500
F6	0.330	75	200
F7	0.262	80	400
F8	0.262	80	275
F9	0.262	80	250

* *Extracted from a data sheet provided by the Continental Felt Company.*

REFERENCES

1. W.P. D'Amico, Jr., "Aeroballistic Testing of the XM825 Projectile: Phase I," Ballistic Research Laboratory Memorandum Report ARBRL-MR-02911, March 1979. AD# B037680L.

2. W.P. D'Amico, "Early Flight Experiences with the XM761," Ballistic Research Laboratory Memorandum Report No. 2791, September 1977. AD# B024975L.

3. W.P. D'Amico, "Field Tests of the XM761: First Diagnostic Test," Ballistic Research Laboratory Memorandum Report No. 2792, September 1977. AD# B024976L.

4. W.P. D'Amico, "Field Tests of the XM761: Second Diagnostic Test," Ballistic Research Laboratory Memorandum Report ARBRL-MR-02806, January 1978. AD# B025305L.

5. W.P. D'Amico, W.H. Clay, and A. Mark, "Diagnostic Tests for Wick-Type Payloads and High Viscosity Liquids," Ballistic Research Laboratory Memorandum Report ARBRL-MR-02913, April 1979. AD# A072812.

6. M.C. Miller, "Flight Instability Test Fixture for Non-Rigid Payloads," Chemical Systems Laboratory Special Publication No. ARCSL-SP-79005, January 1979. AD# A030-430.

7. W.P. D'Amico and W.H. Clay, "Flight Tests for Prototype Felt Wedge/White Phosphorous Improved Smoke Concept," Ballistic Research Laboratory Memorandum Report ARBRL-MR-02824, April 1978. AD# A054643.

8. W.H. Mermagen and W.H. Clay, "The Design of a Second Generation Yawsonde," Ballistic Research Laboratory Memorandum Report No. 2368, April 1974. AD# 780064.

9. C.H. Murphy, "Effect of Large High-Frequency Angular Motion of a Shell on the Analysis of Its Yawsonde Records," Ballistic Research Laboratory Memorandum Report No. 2581, February 1976. AD# B0094210.

10. J.H. Whiteside, "Flight Behavior Test of 155mm XM687E1 and XM718E1 and 8-Inch XM650E4, PXR6231, XM711 and XM736 Shell at Nicolet, Canada, During the Winter of 1975-1976," Ballistic Research Laboratory Memorandum Report No. 2732, March 1977. AD# B018149L.

11. V. Oskay and J.H. Whiteside, "1974-1975 Winter Tests of 155mm (M483 Family) and 8-Inch (M509 Family) High-Capacity Shell at Nicolet, Canada," Ballistic Research Laboratory Memorandum Report No. 2723, January 1977. AD# B017015L.

REFERENCES (continued)

12. W.P. D'Amico, "XM803 Yawsonde Reduction," Ballistic Research Laboratory Memorandum Report in publication.

13. A. Mark and W.H. Clay, "Aeroballistic Test of the XM802 RP Smoke Projectile," Ballistic Research Laboratory Memorandum Report ARBRL-MR-02877, November 1978. AD# B033753L.

LIST OF SYMBOLS

A_{mn}	a ratio of K_{10} amplitudes, Eq. 6
C_{M_α}	static moment coefficient
d	maximum diameter of projectile
I_x	axial moment of inertia of the projectile
I_y	transverse moment of inertia of projectile
K_j	length of the jth modal arm, j=1,2
n	twist of rifling
p	axial spin rate
s	arc length along trajectory
s_g	gyroscopic stability factor
V	speed of projectile relative to air

GREEK LETTERS

ξ	the complex yaw
ρ	air density
σ	$(1 - 1/s_g)^{1/2}$
ϕ_j	orientation angle for the jth modal arm, j=1,2
ϕ'_j	frequency of the jth modal arm, j=1,2

SUBSCRIPTS

j	slower precessional mode (j=2), faster precessional mode (j=1)

SPECIAL NOTATION

$(\ )'$	derivative with respect to arc length

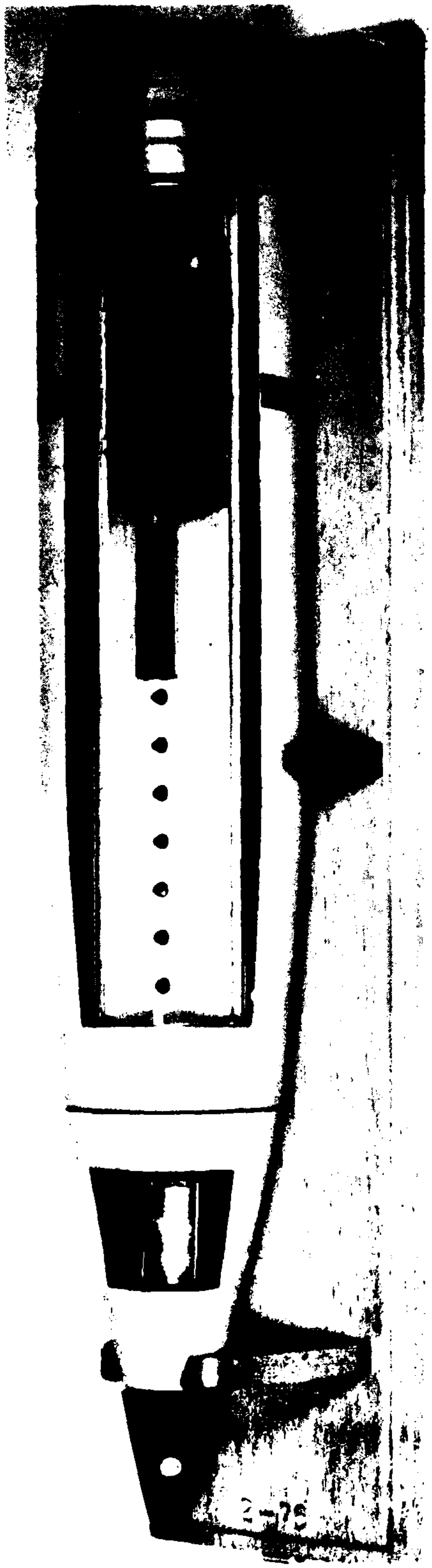

Figure 1. Cut-away view of the XM825 projectile.

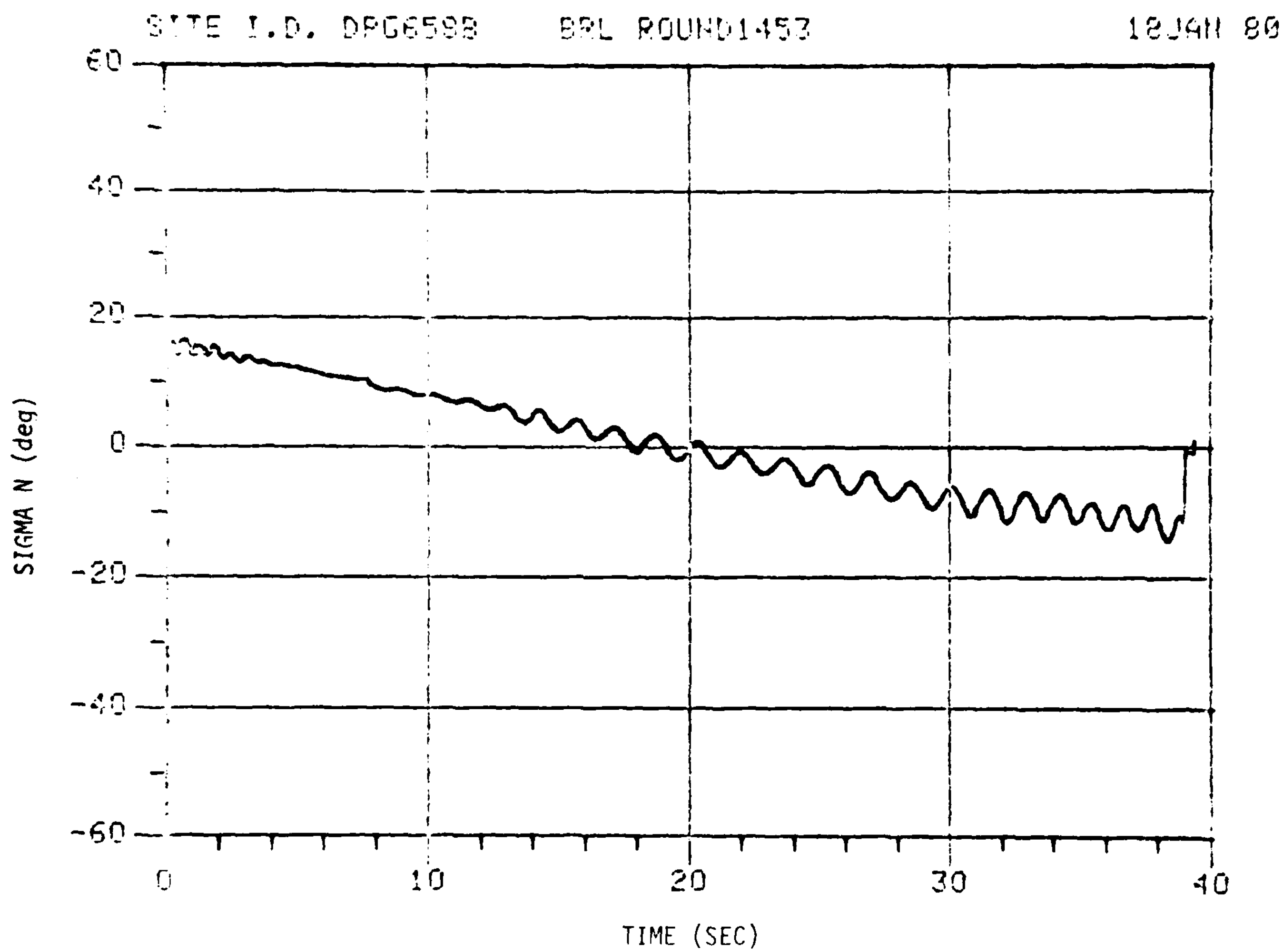

Figure 2. SIGMA N versus Time - DPG 658B.

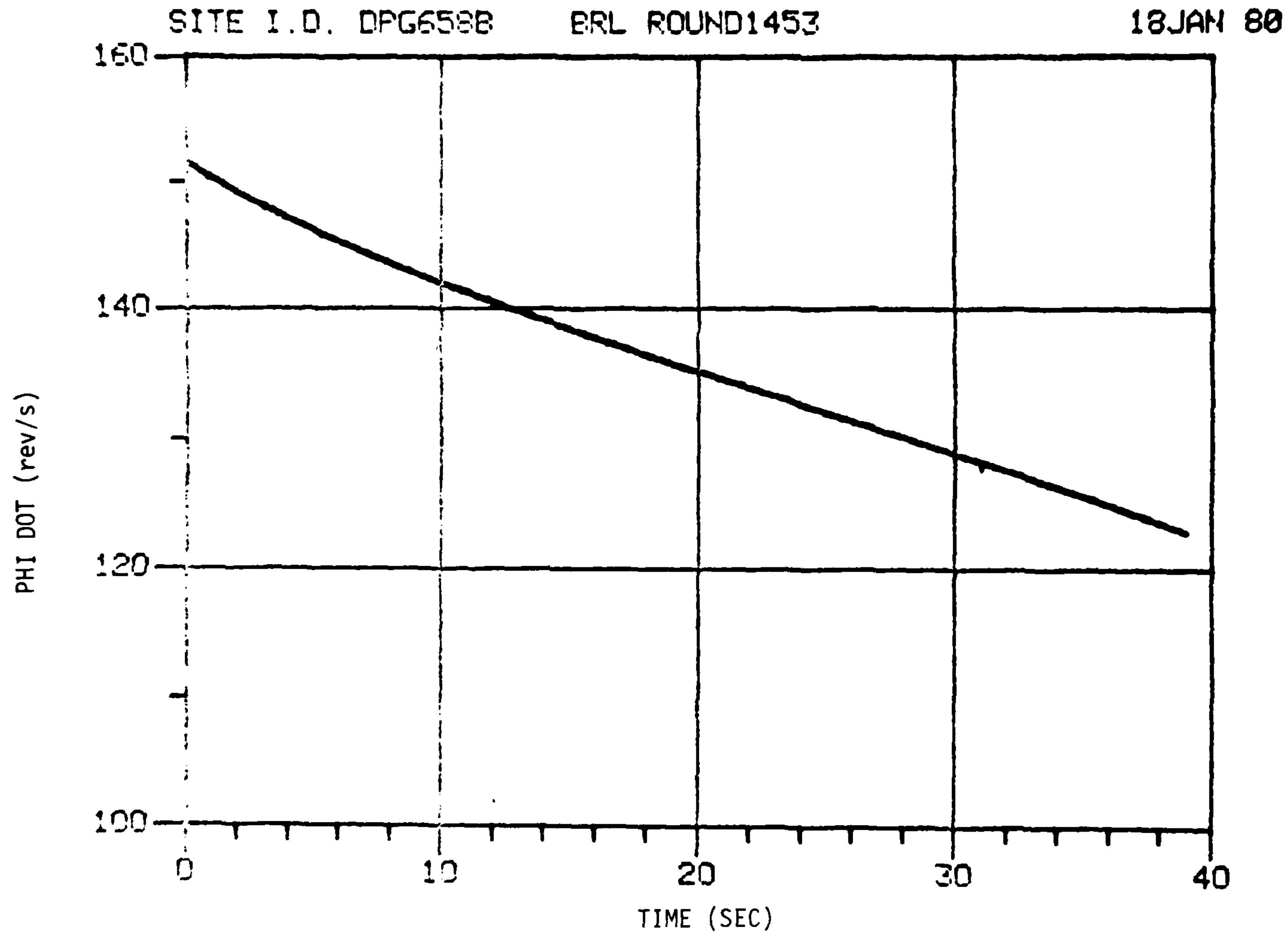

Figure 3. PHI DOT versus Time - DPG 658B.

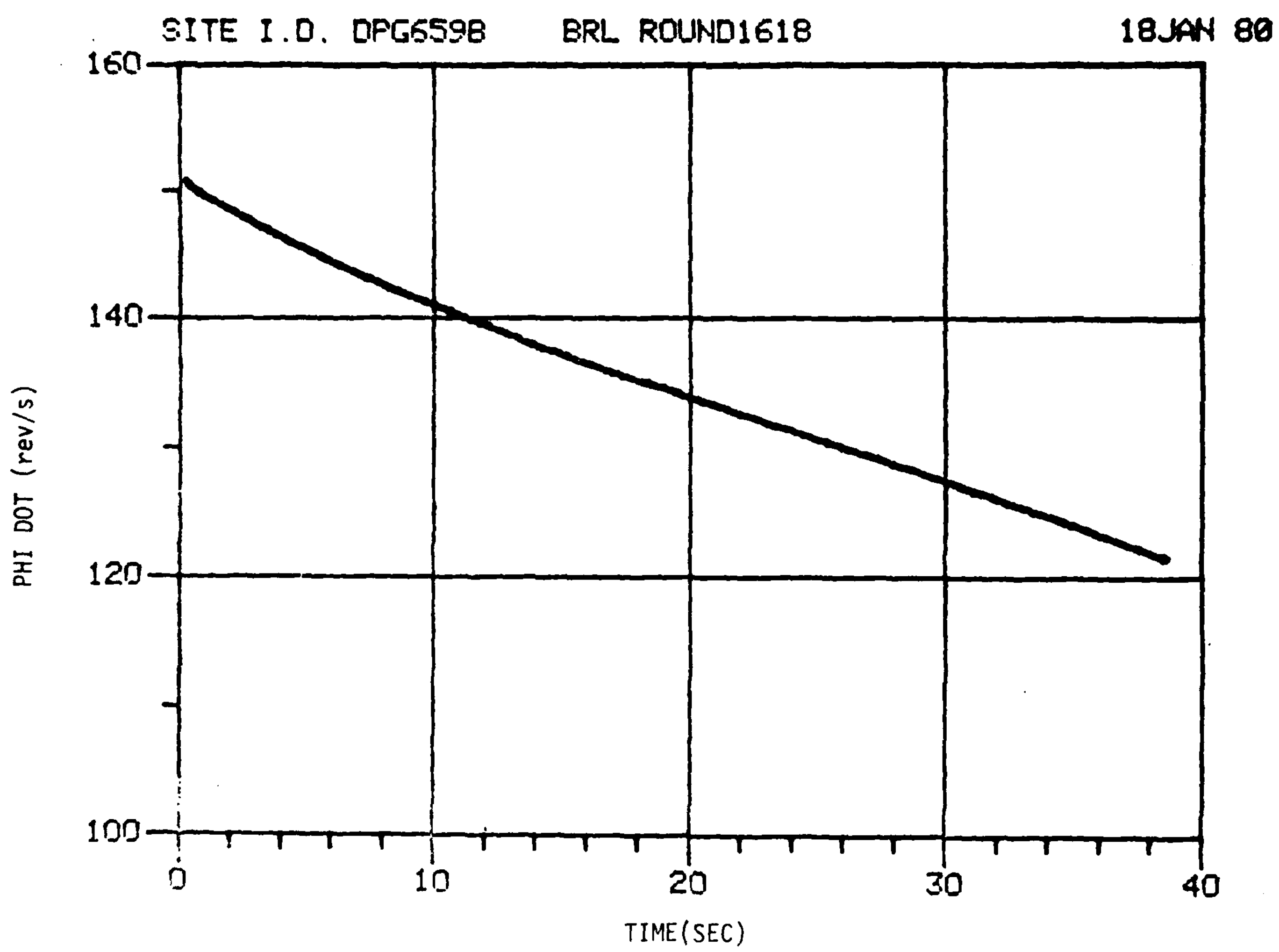

Figure 4. PHI DOT versus Time - DPG 659B.

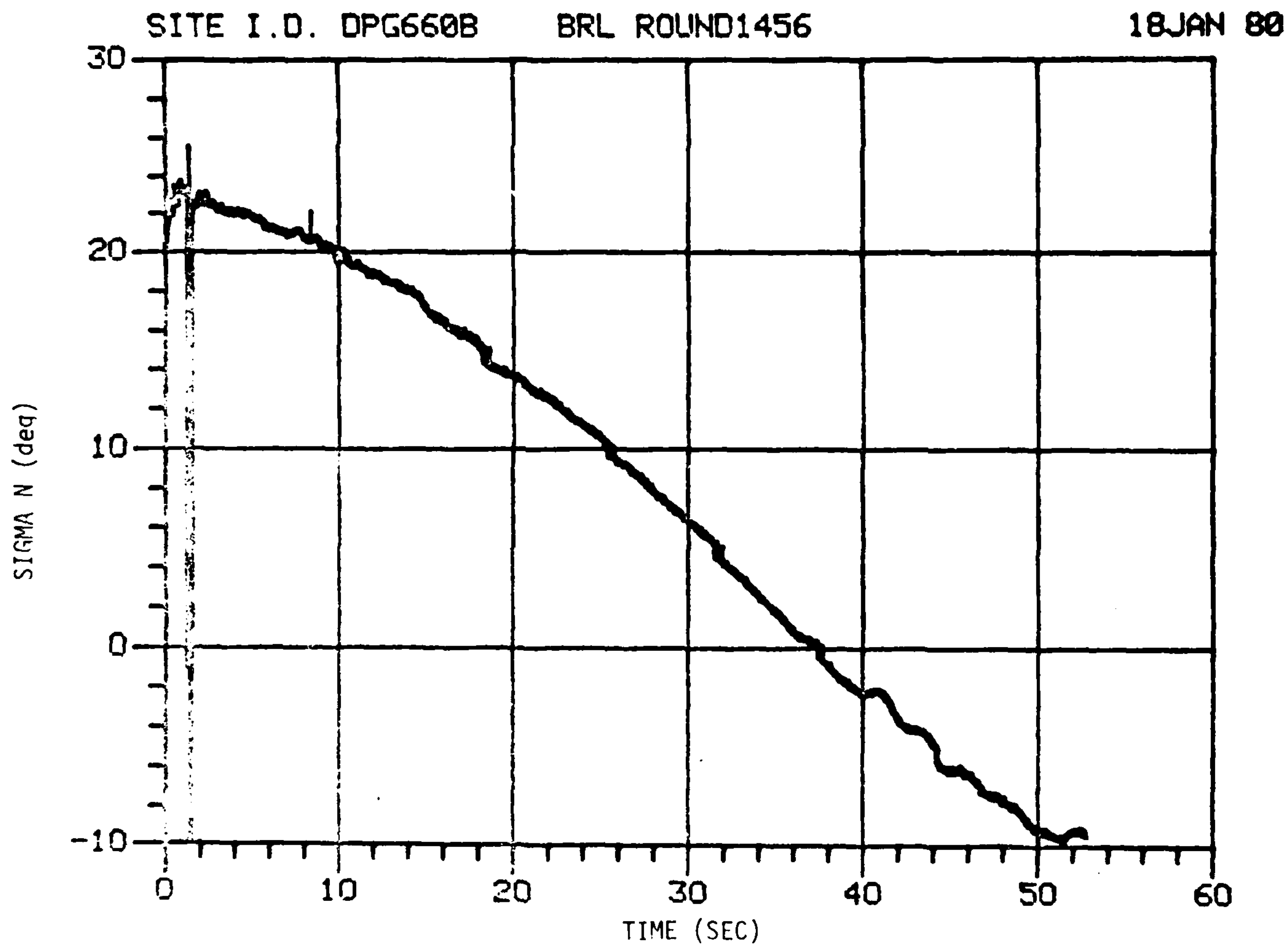

Figure 5. SIGMA N versus Time - DPG 660B.

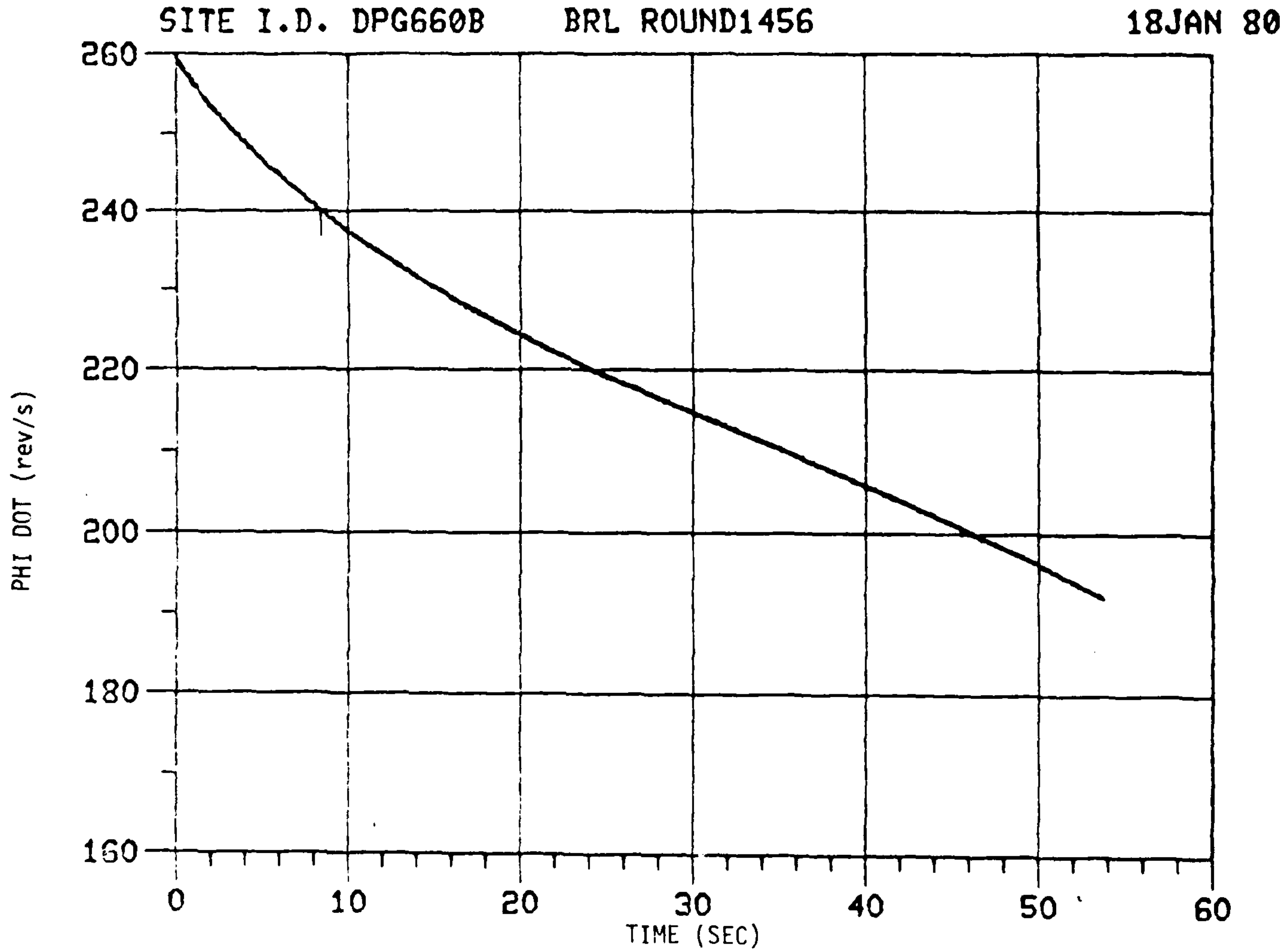

Figure 6. PHI DOT versus Time - DPG 660B.

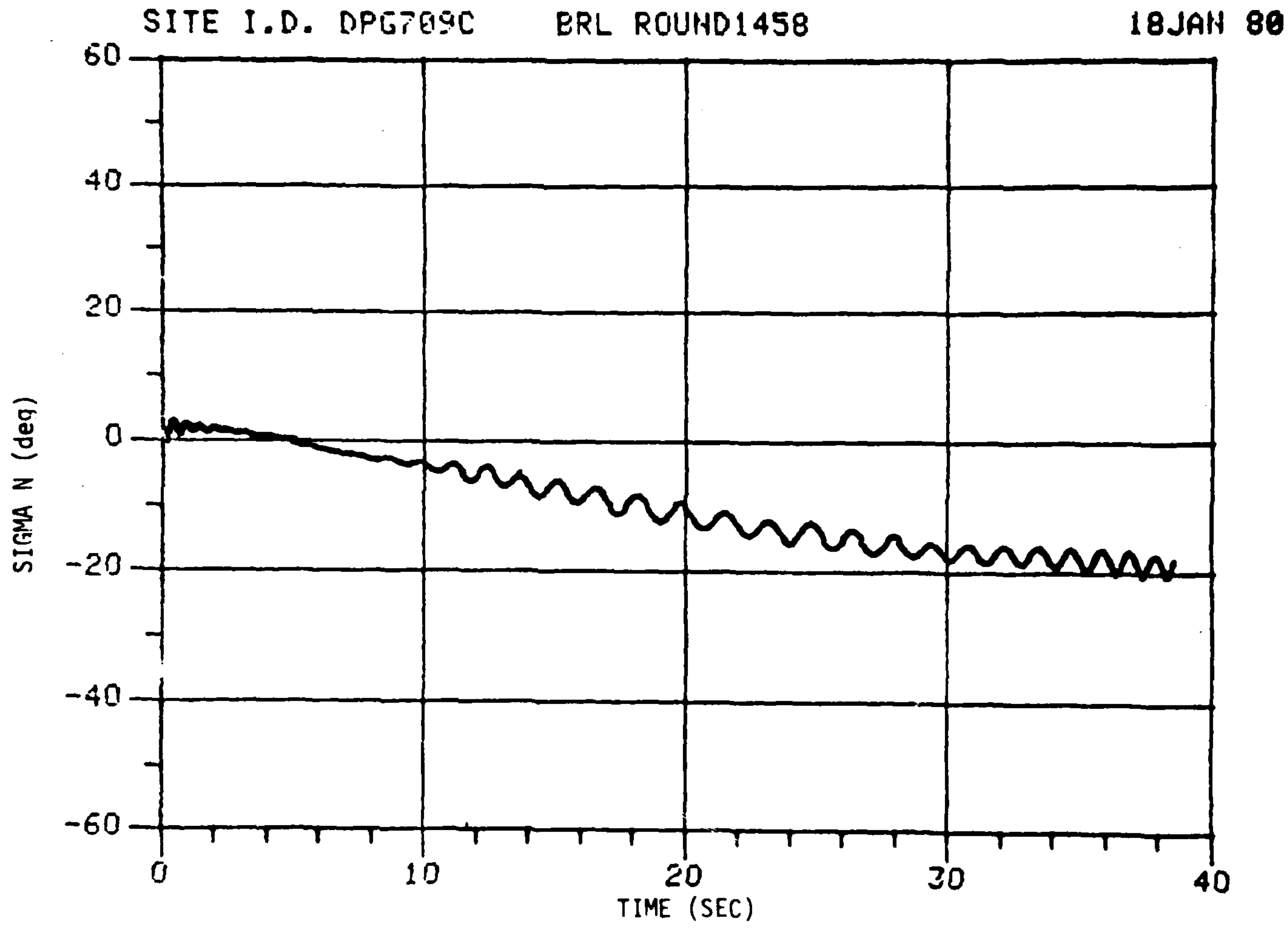

Figure 7. SIGMA N versus Time - DPG 709C.

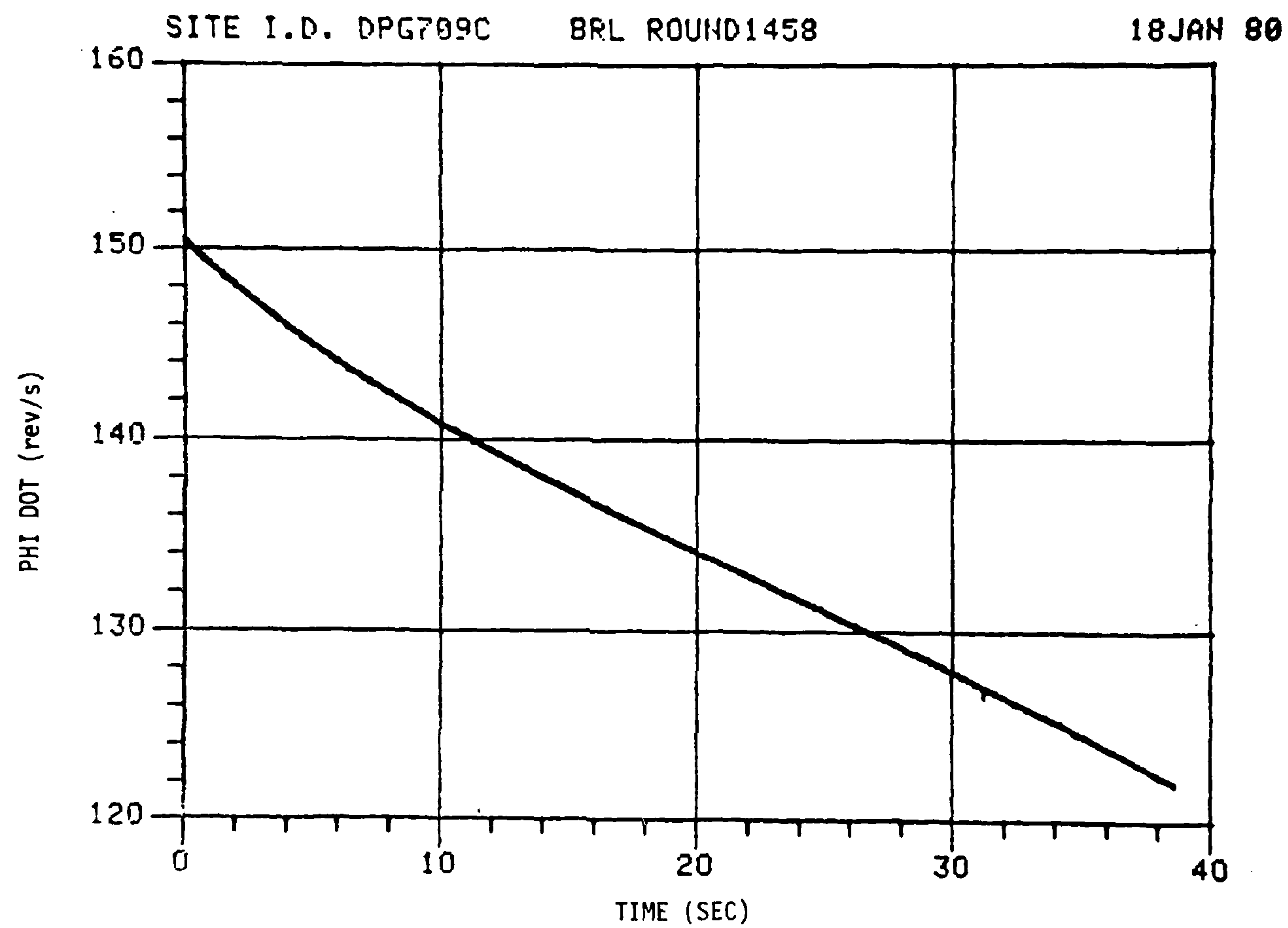

Figure 8. PHI DOT versus Time - DPG 709C.

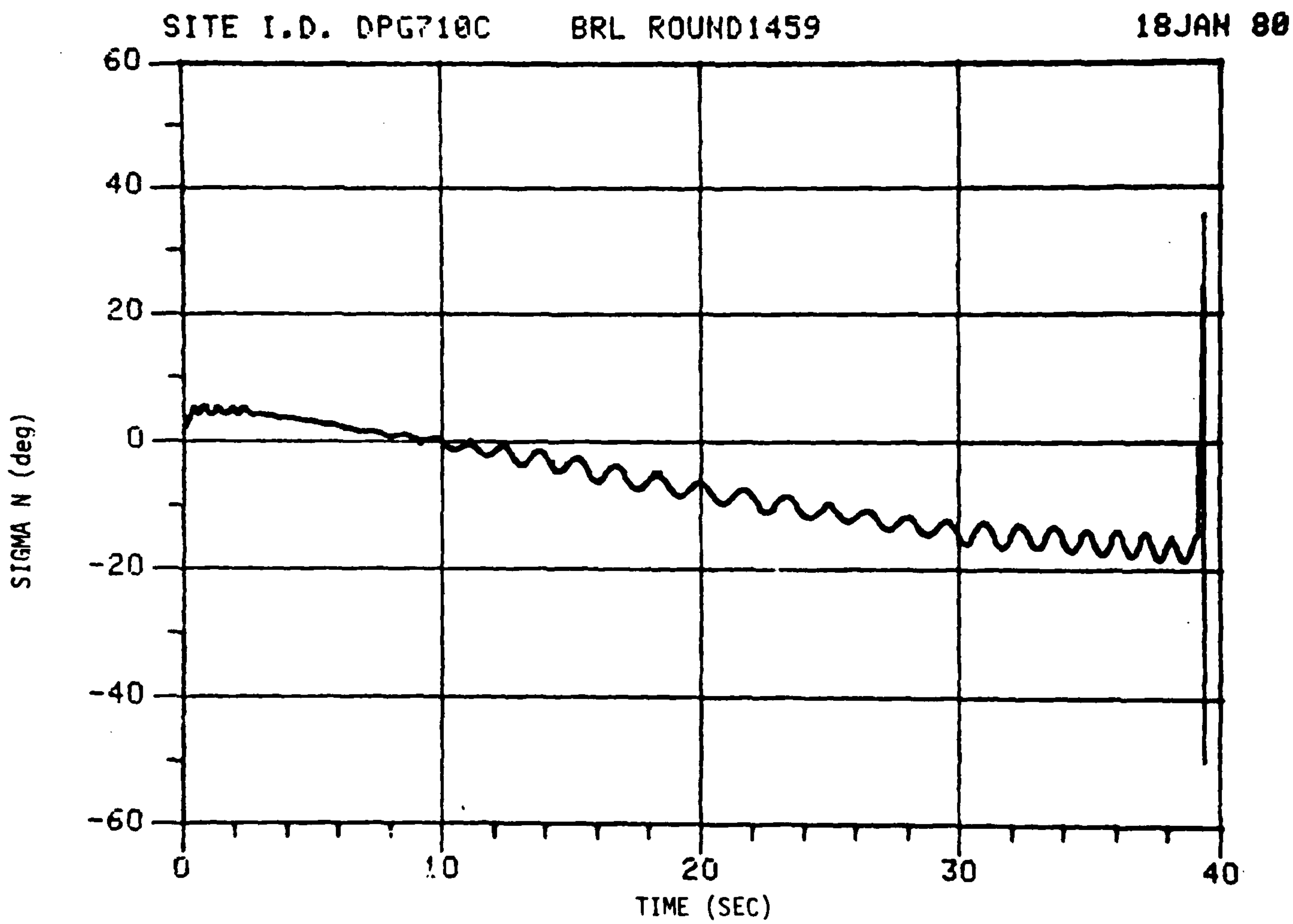

Figure 9. SIGMA N versus Time - DPG 710C.

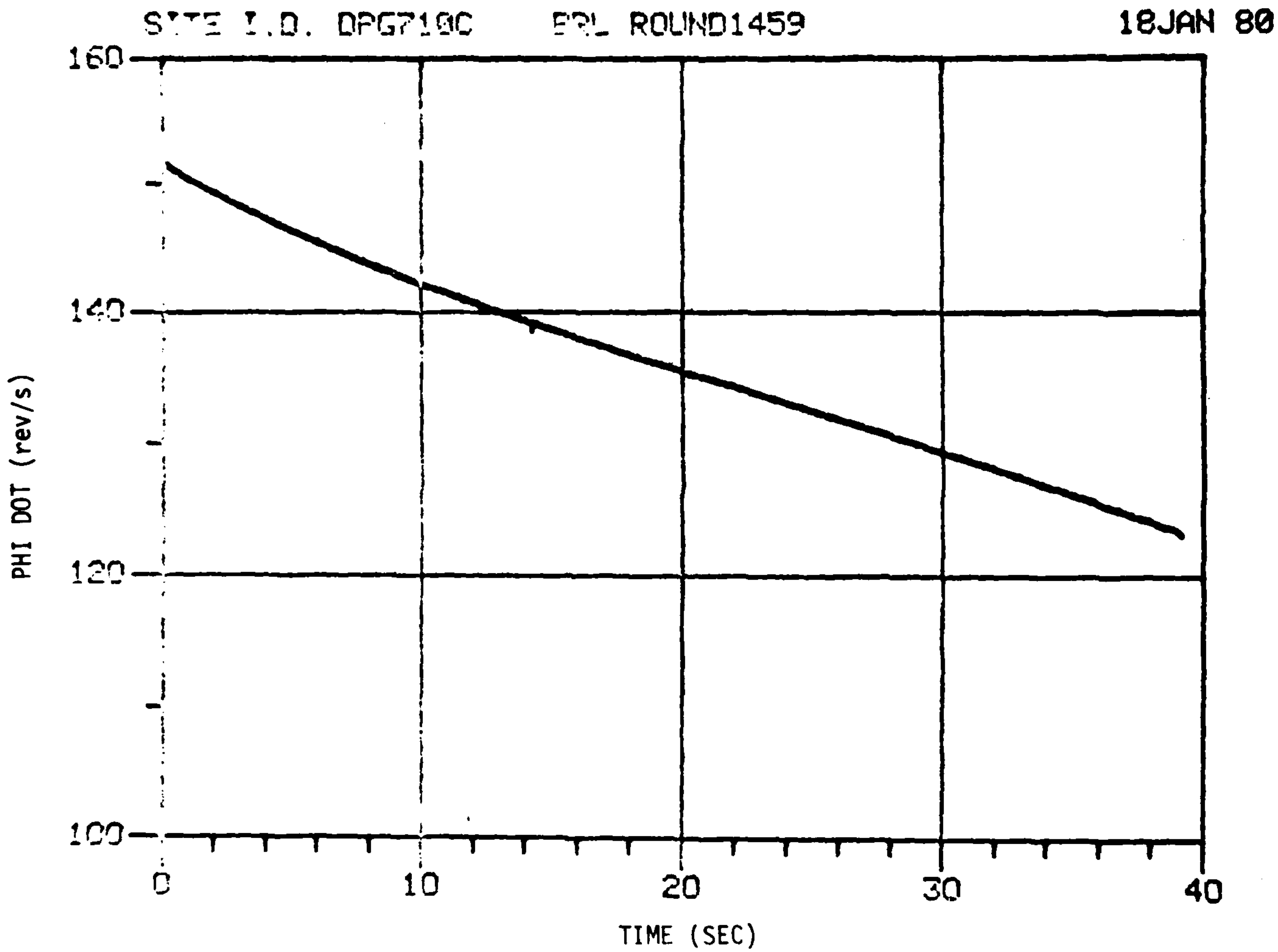

Figure 10. PHI DOT versus Time - DPG 710C.

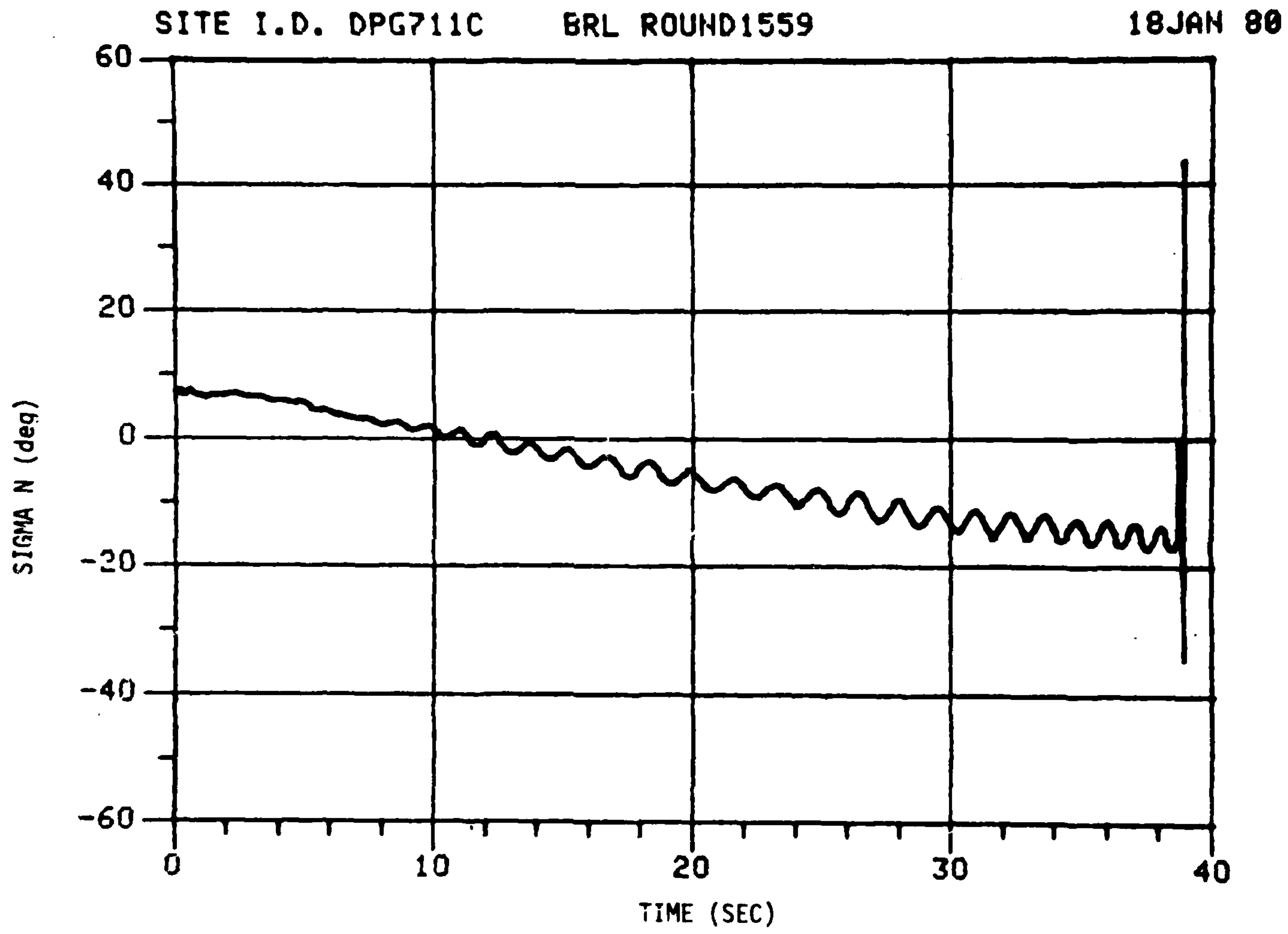

Figure 11. SIGMA N versus Time - DPG 711C.

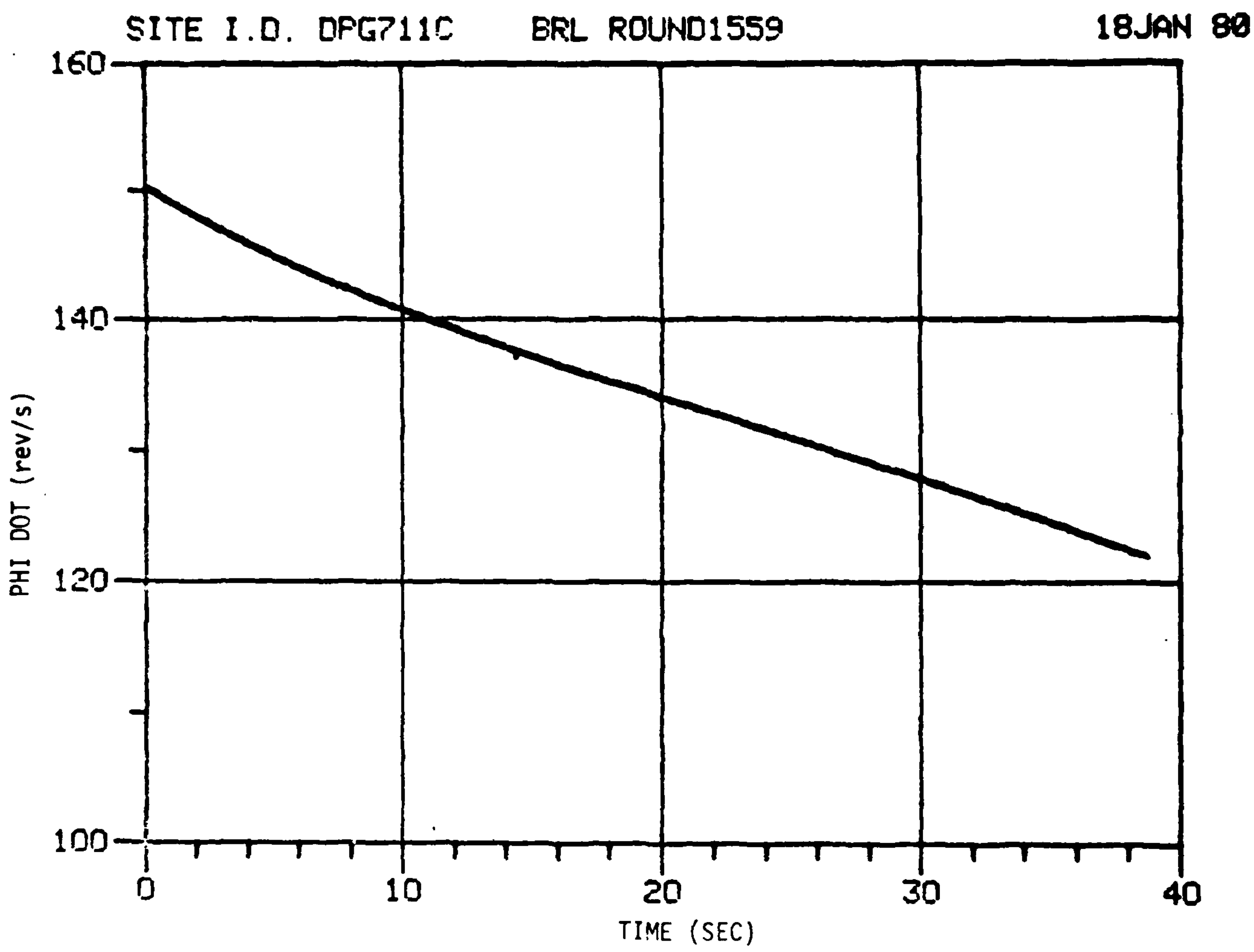

Figure 12. PHI DOT versus Time - DPG 711C.

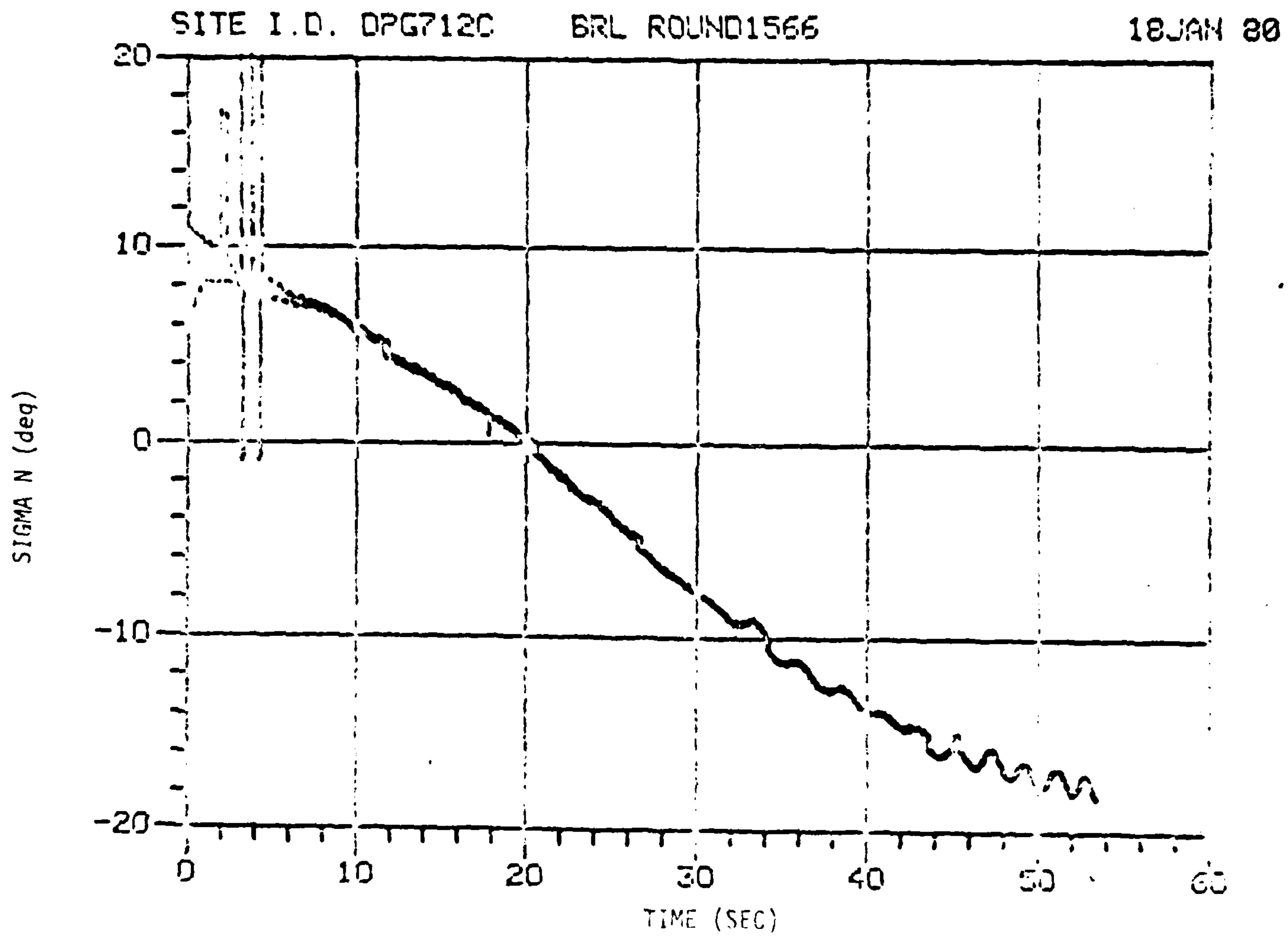

Figure 13. SIGMA N versus Time - DPG 712C.

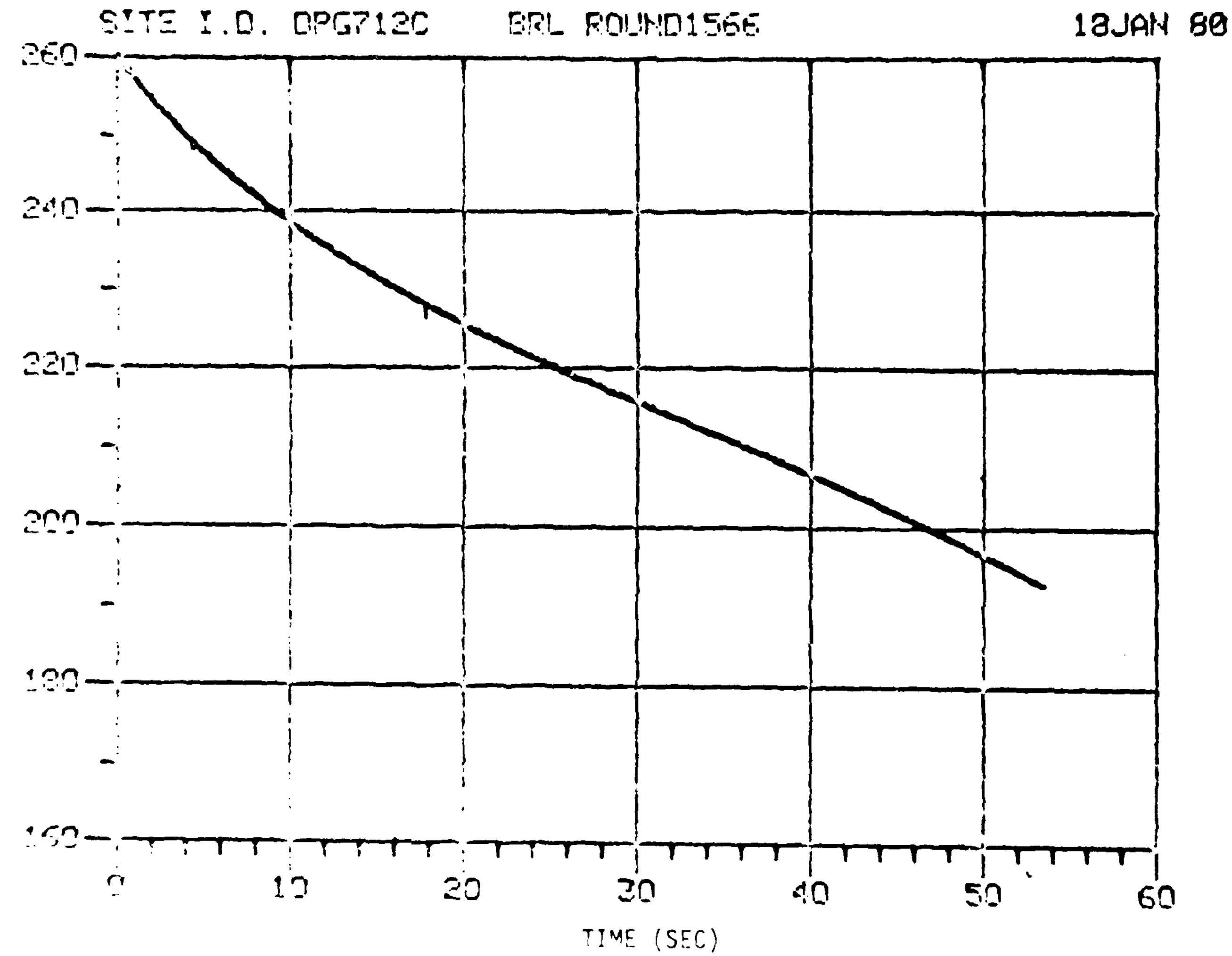

Figure 14. PHI DOT versus Time - OPG 712C.

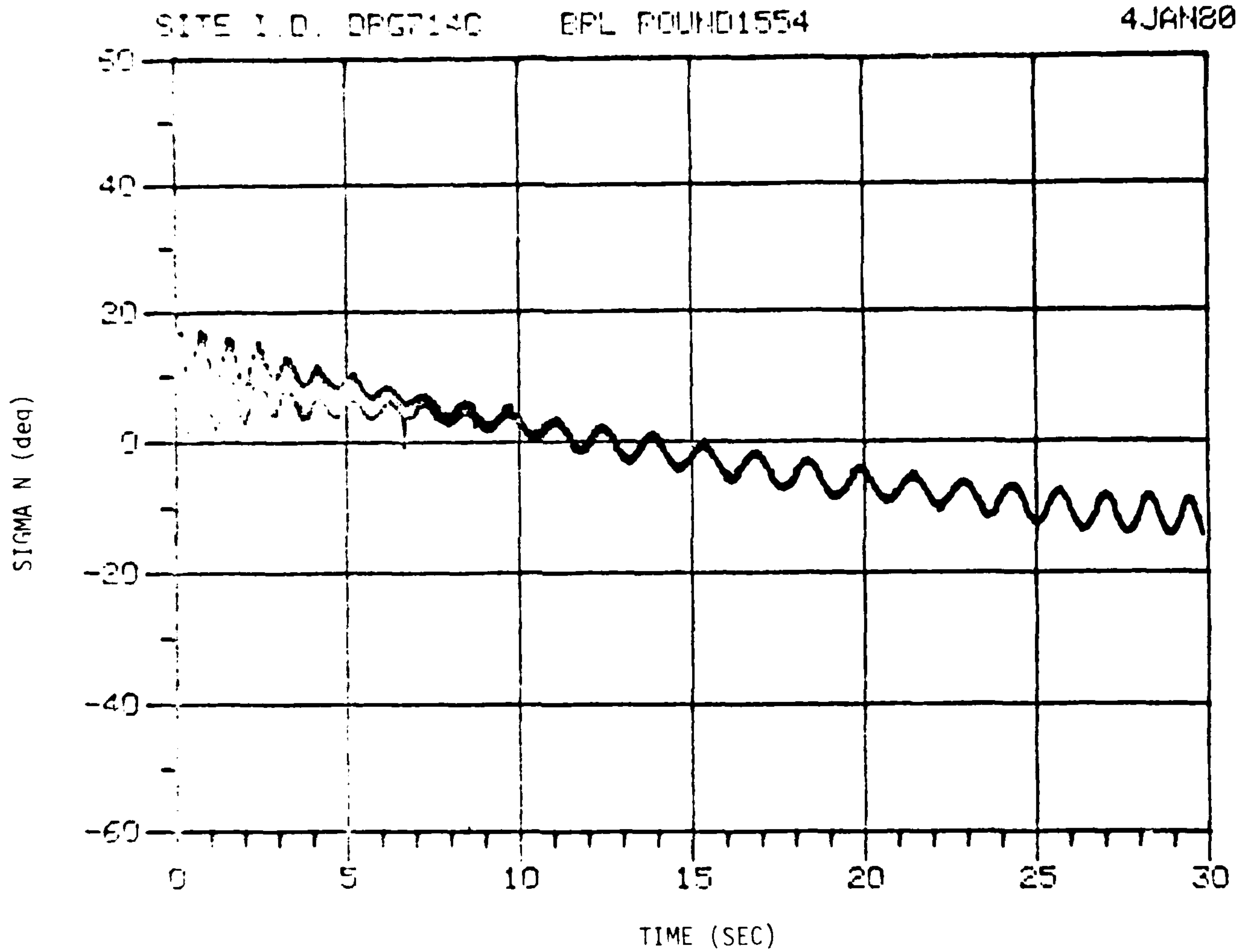

Figure 15a. SIGMA N versus Time - DPG 714C.

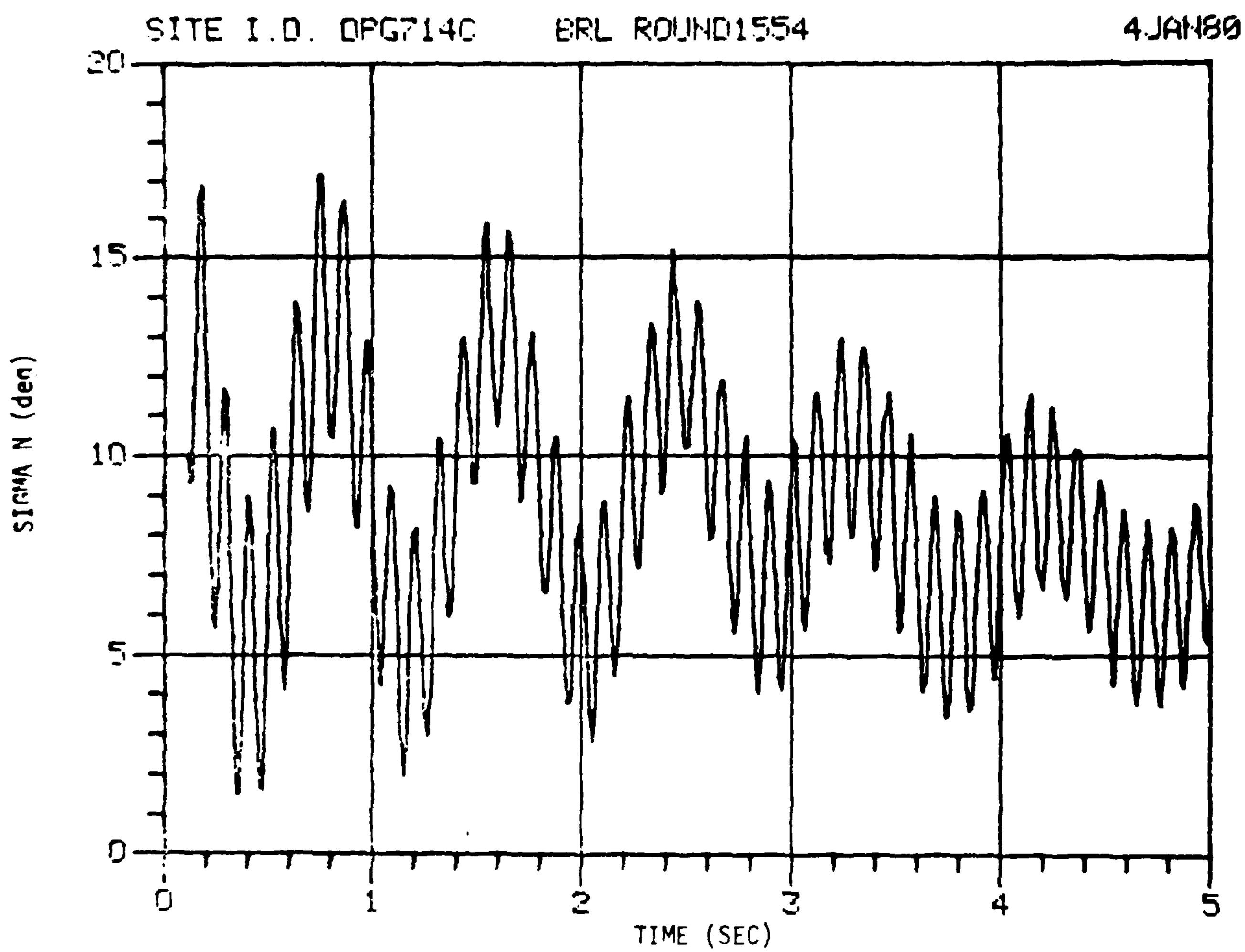

Figure 15b. SIGMA N versus Time - DPG 714C.

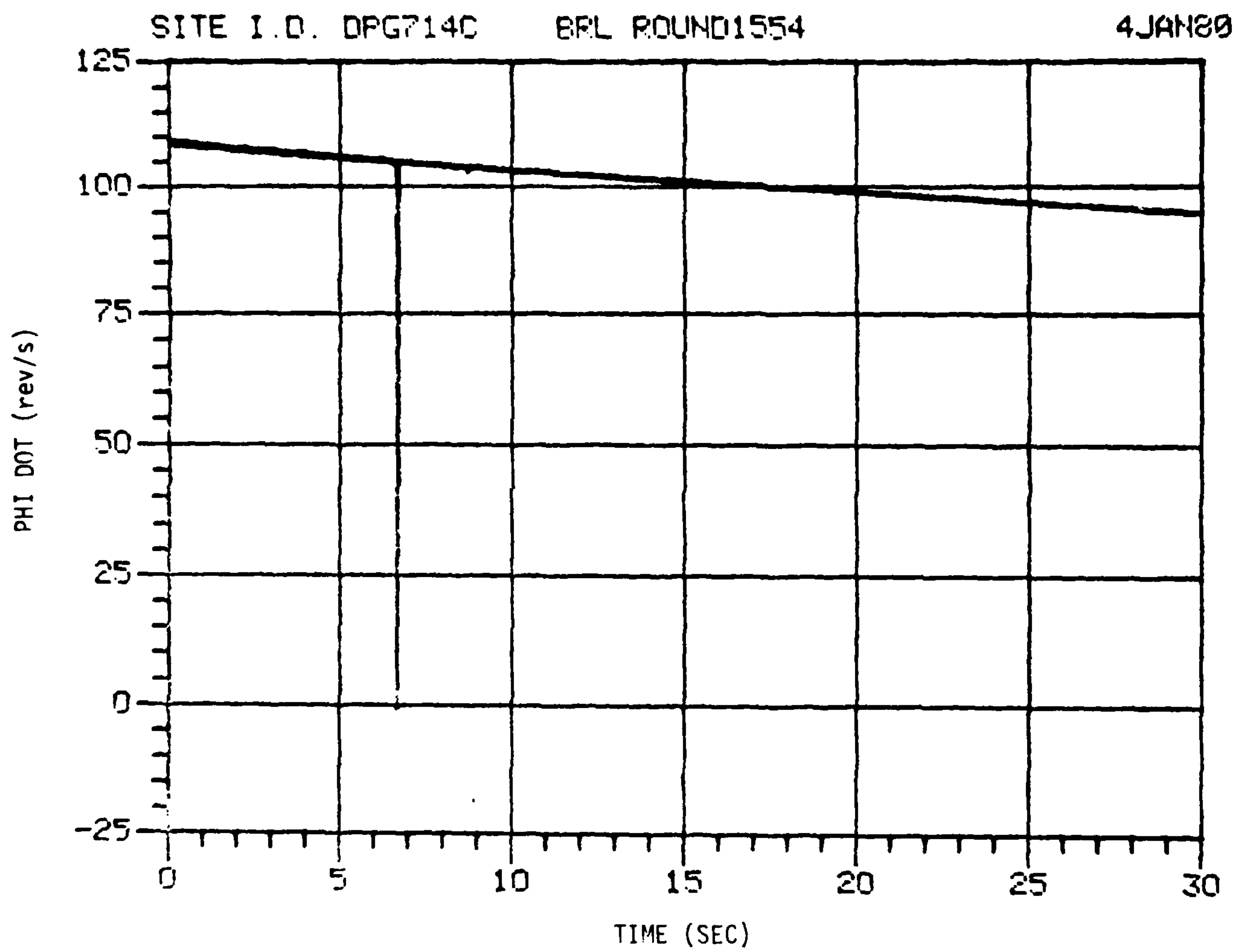

Figure 16. PHI DOT versus Time - DPG 714C.

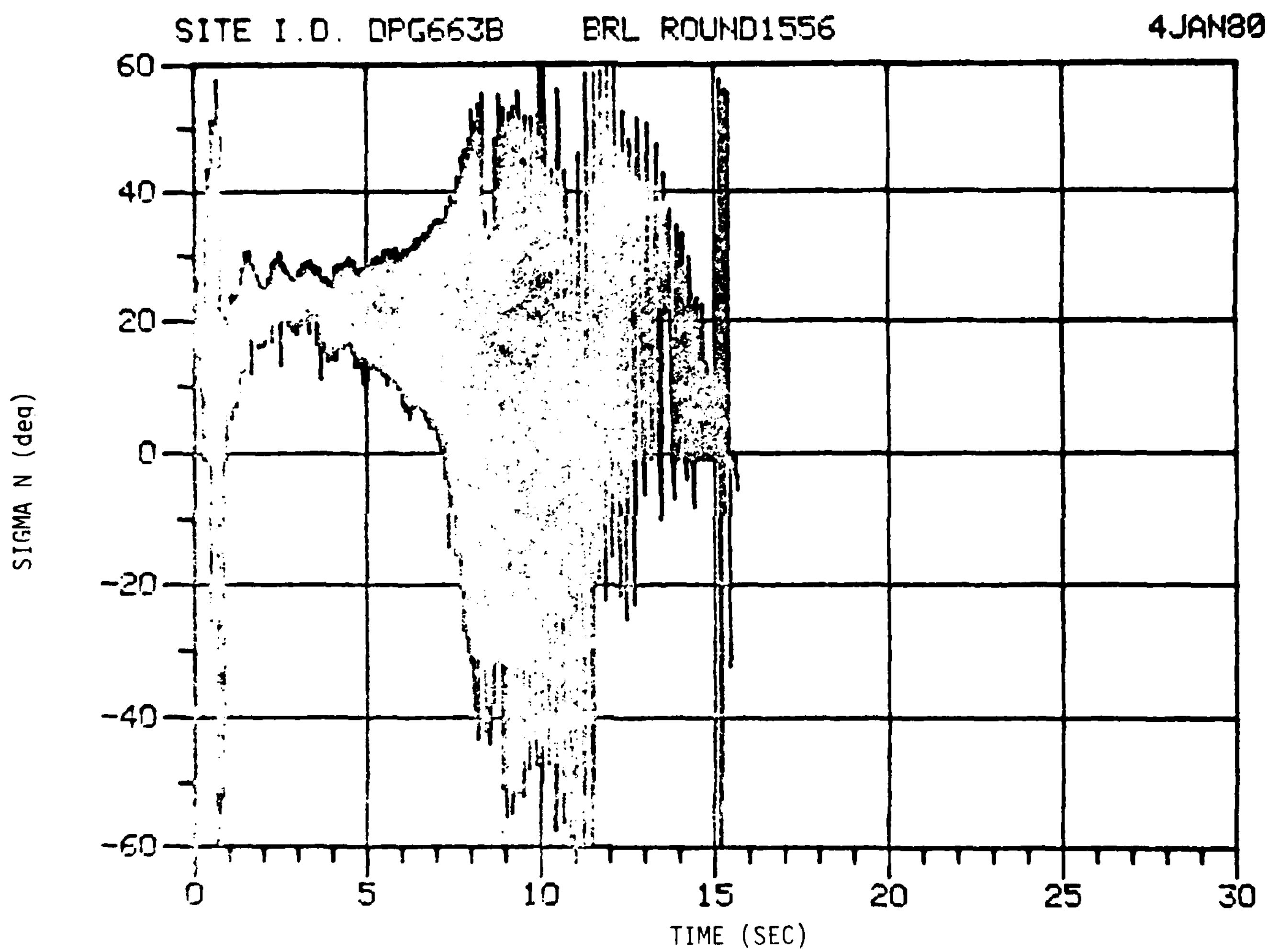

Figure 17. SIGMA N versus Time - DPG 663B.

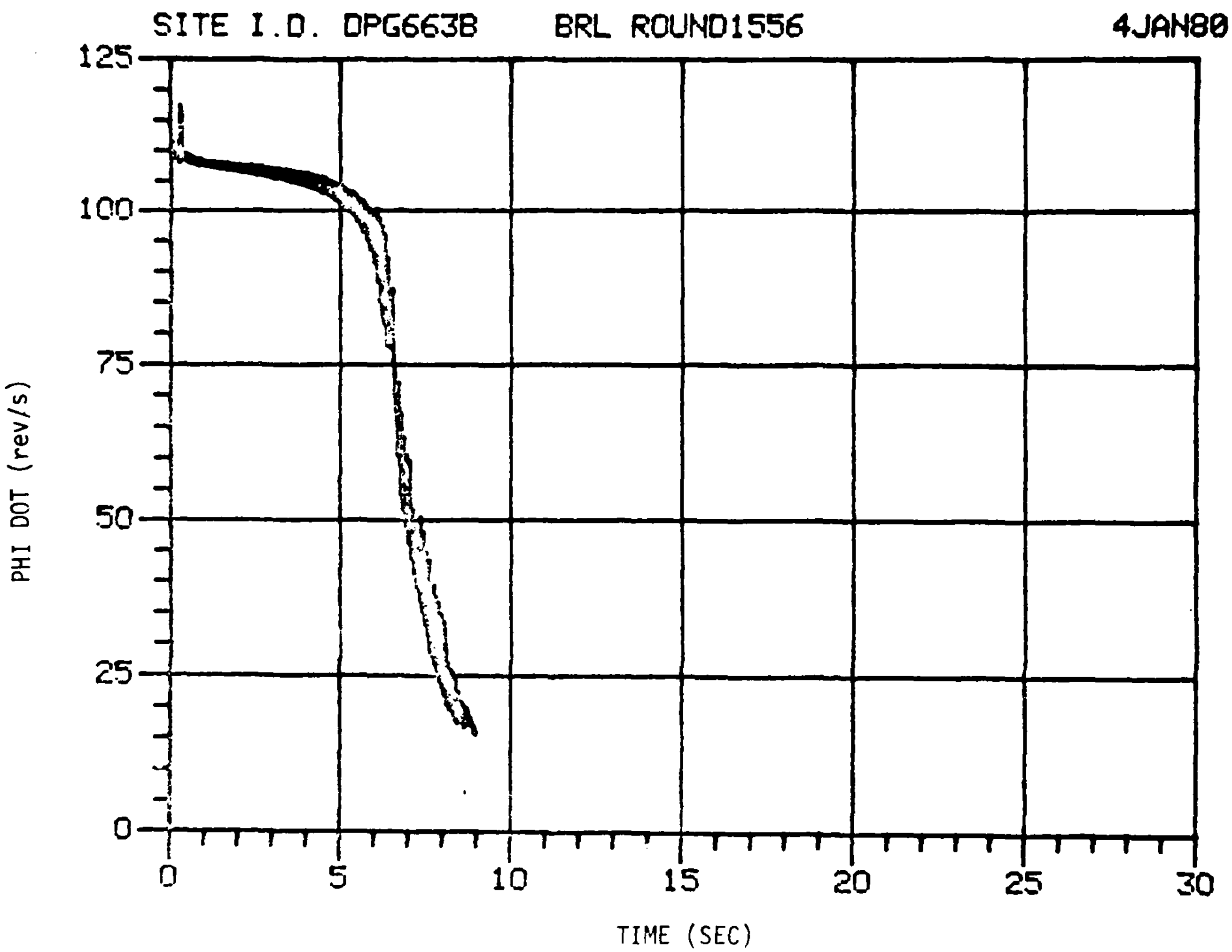

Figure 18. PHI DOT versus Time - DPG 663B.

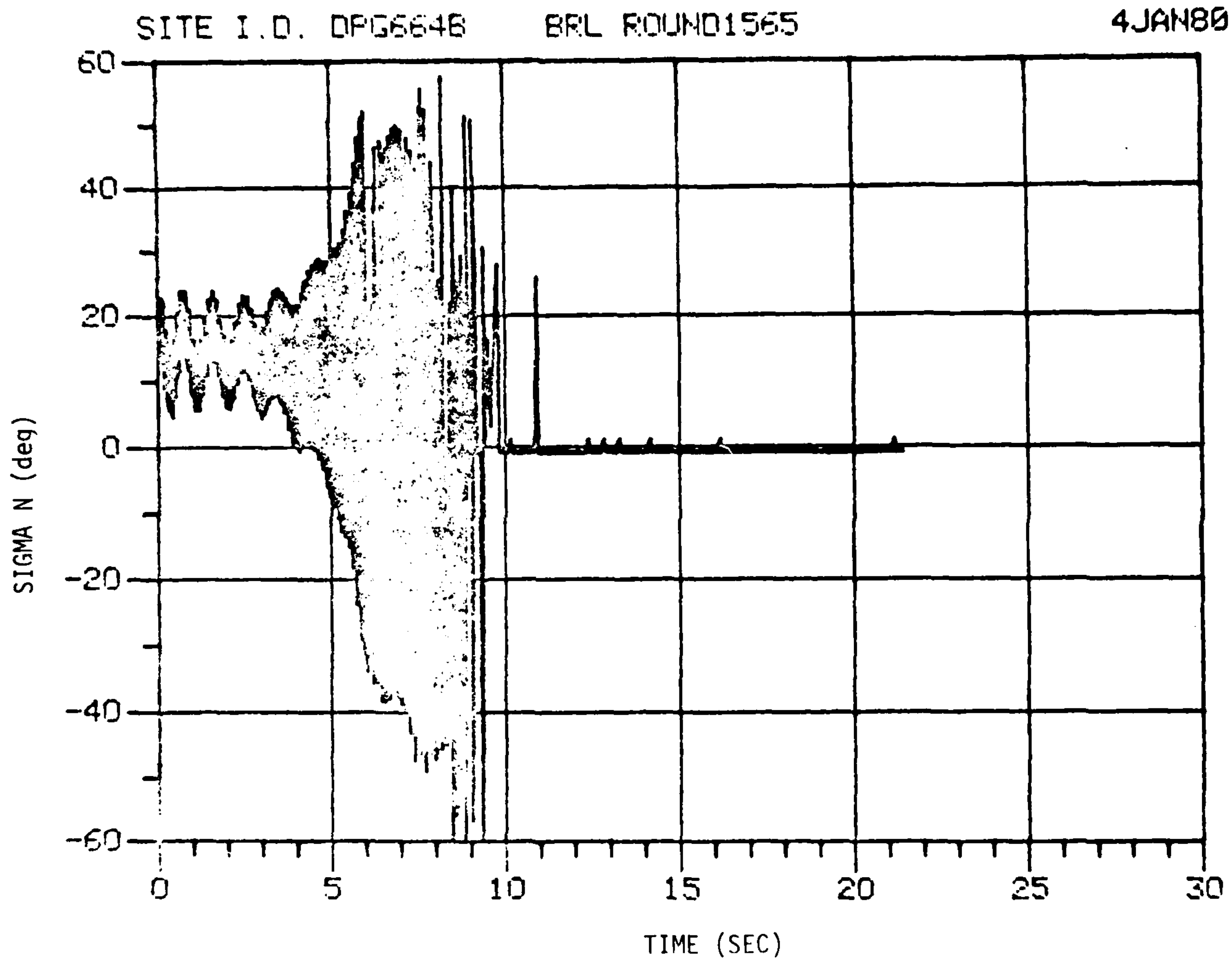

Figure 19a. SIGMA N versus Time - DPG 664B.

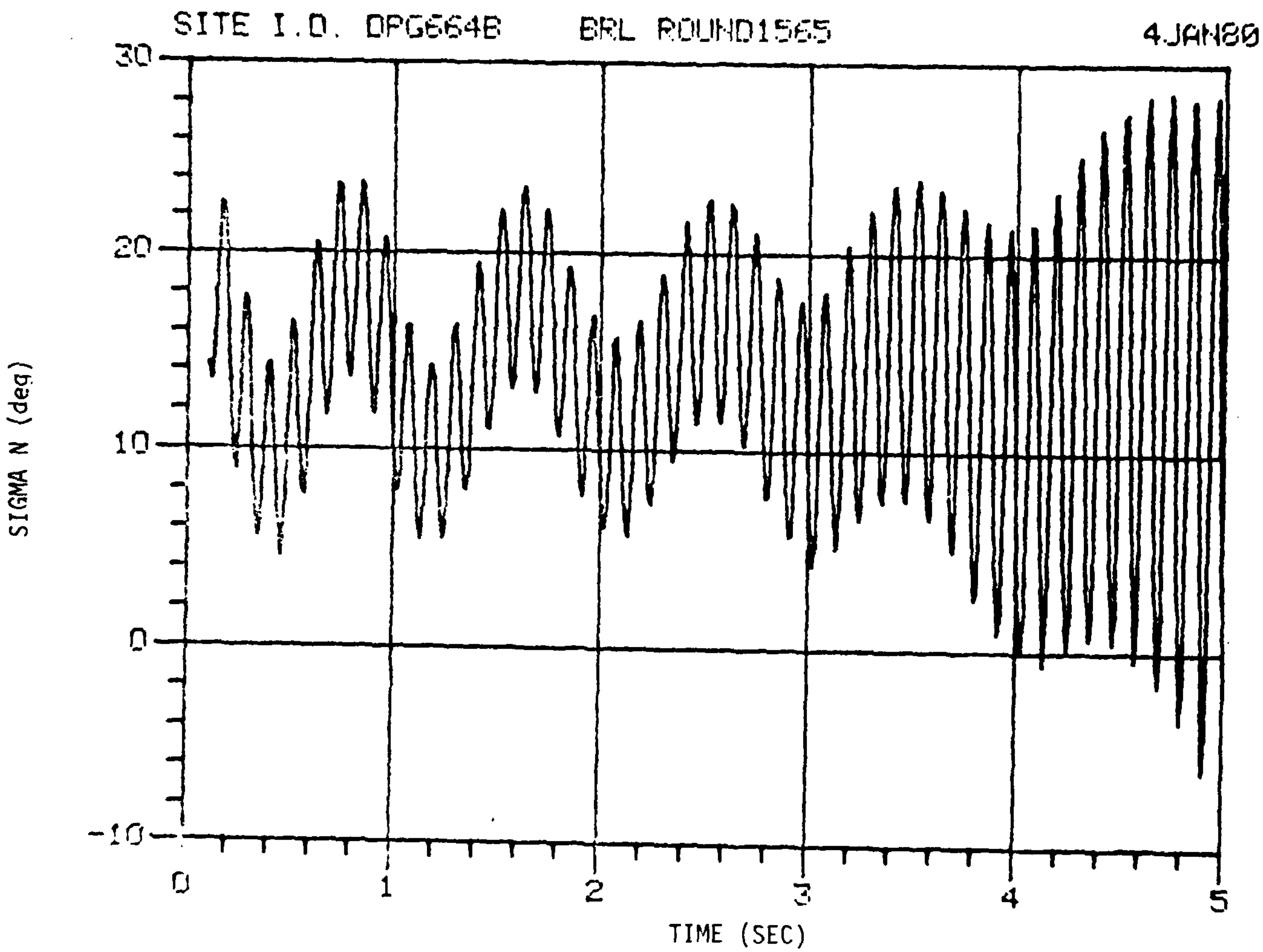

Figure 19b. SIGMA N versus Time - DPG 664B.

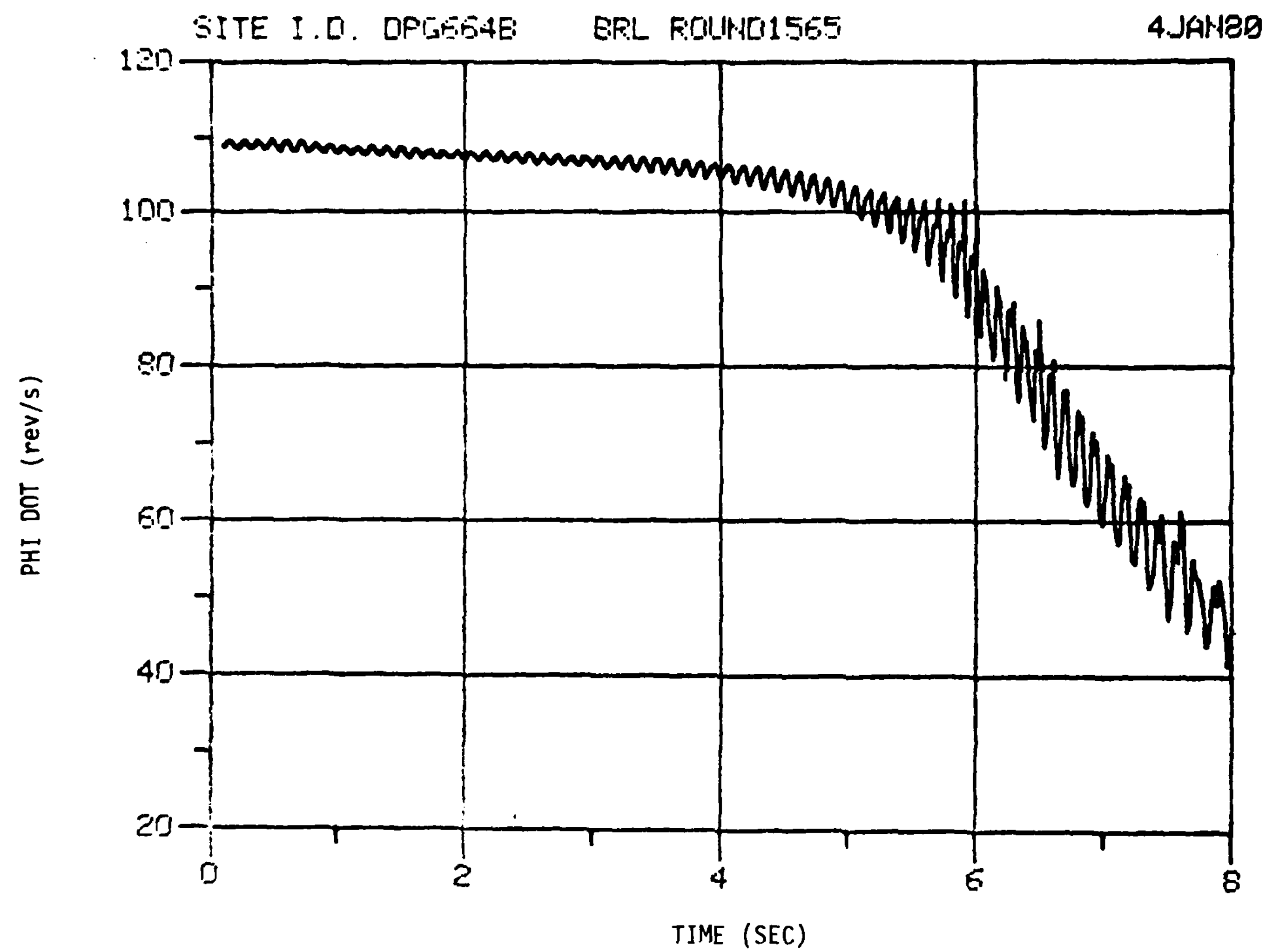

Figure 20. PHI DOT versus Time - DPG 664B.

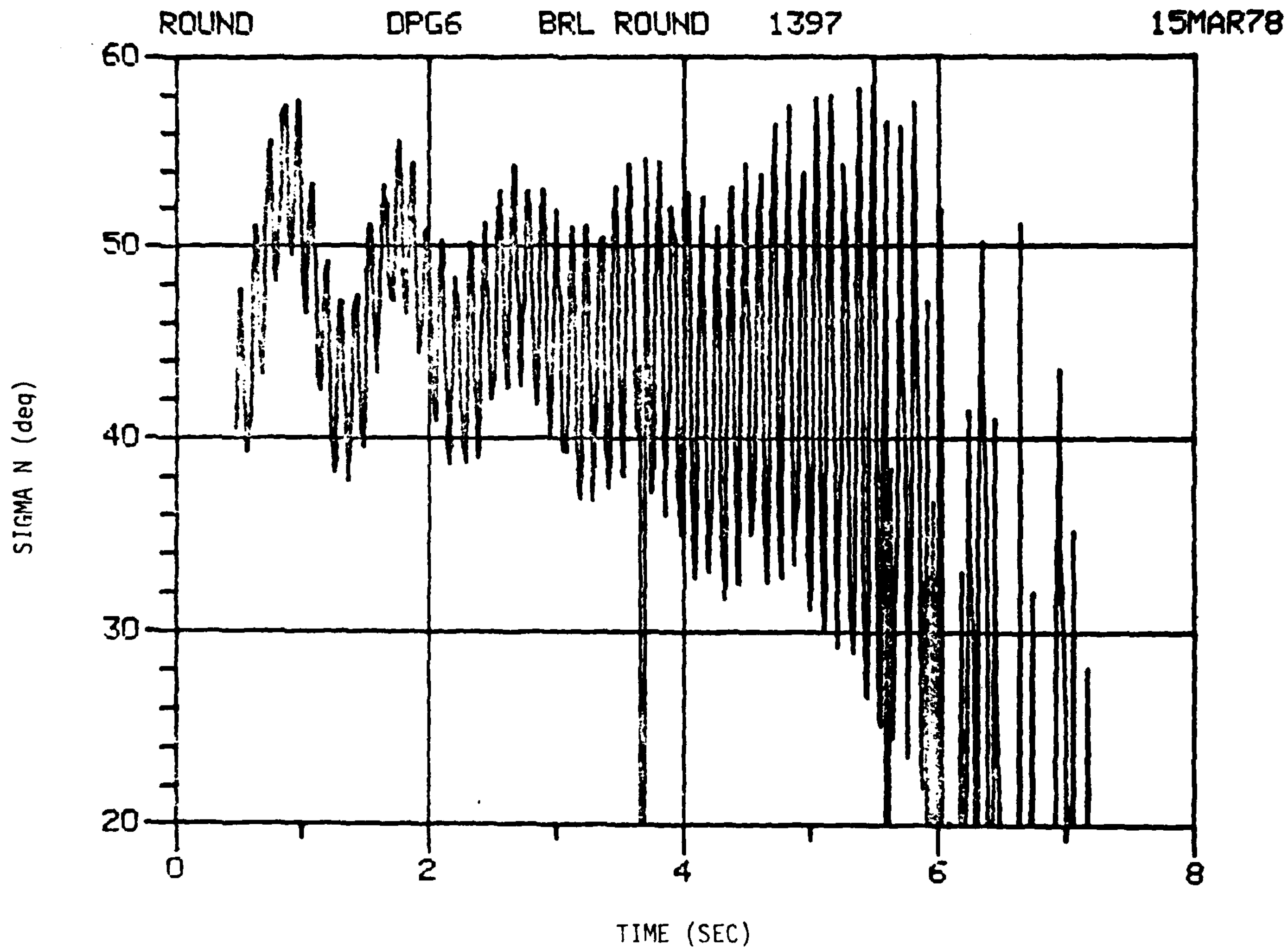

Figure 21. SIGMA N versus Time - DPG6

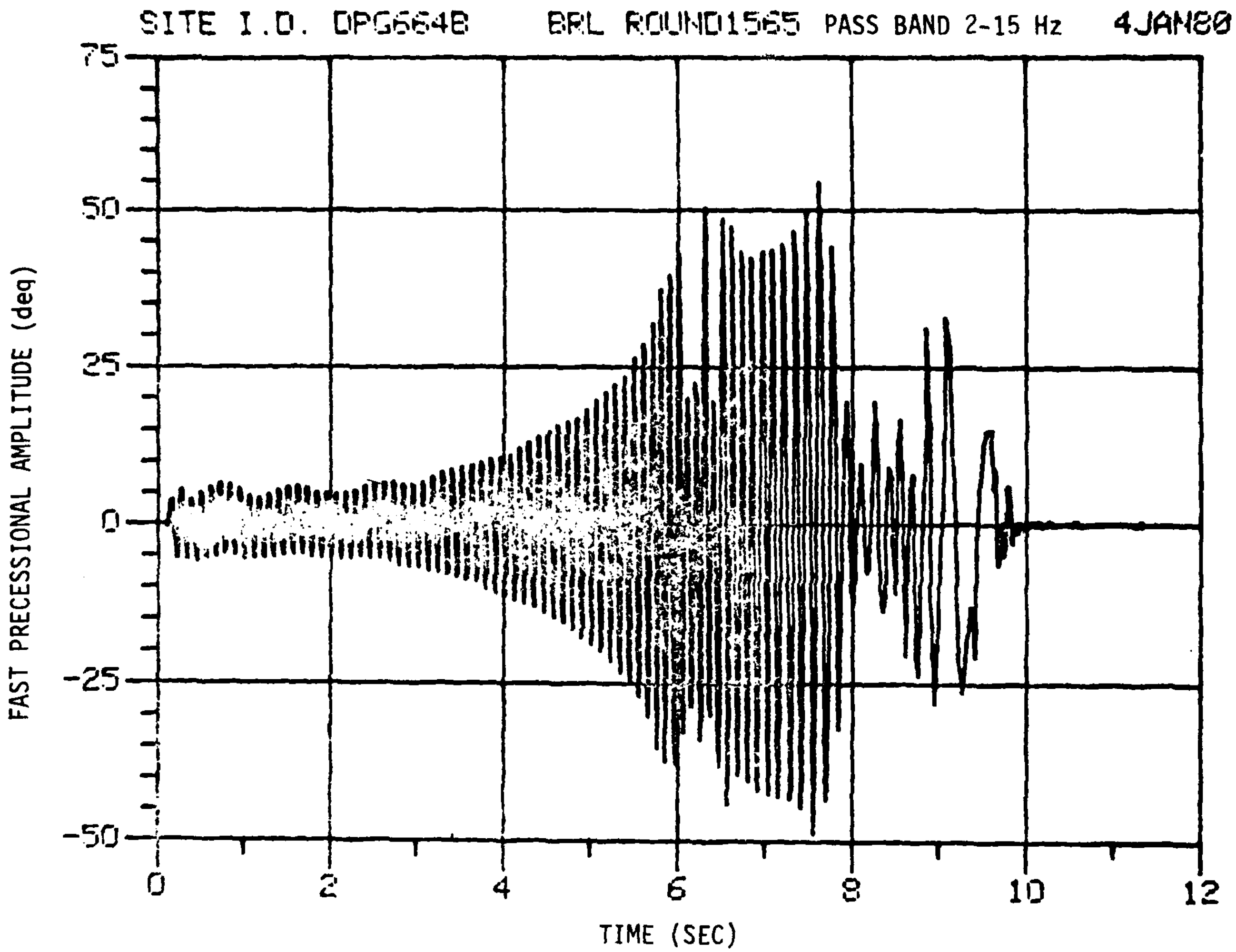

Figure 22. Fast Precessional Amplitude versus Time - DPG 664B.

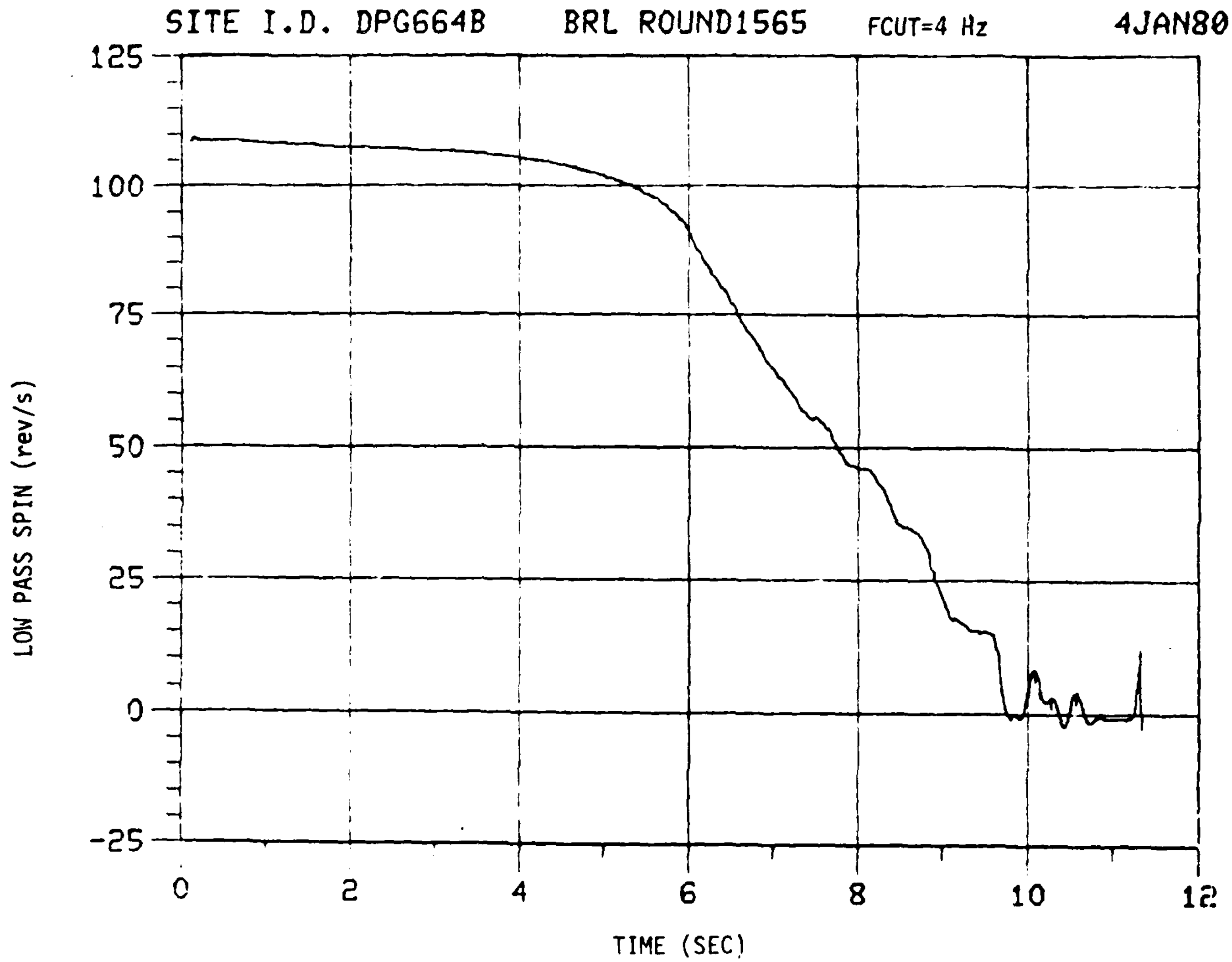

Figure 23. Low Pass Spin versus Time - DPG 664B.

DISTRIBUTION LIST

No. of Copies	Organization	No. of Copies	Organization
12	Commander Defense Technical Info Center ATTN: DDC-DDA Cameron Station Alexandria, VA 22314	1	Commander US Army Communications Research and Development Command ATTN: DRDCO-PPA-SA Fort Monmouth, NJ 07703
1	Commander US Army Materiel Development & Readiness Command ATTN: DRCDMD-ST 5001 Eisenhower Avenue Alexandria, VA 22333	1	Commander US Army Electronics Research and Development Command Technical Support Activity ATTN: DELSD-L Fort Monmouth, NJ 07703
6	Commander US Army Armament Research & Development Command ATTN: DRDAR-TSS (2 cys) DRDAR-LC, Dr. Frasier DRDAR-LCA-F, A. Loeb D. Mertz DRDAR-TDS, V. Lindner Dover, NJ 07801	1	Commander US Army Missile Command ATTN: DRSMI-R Redstone Arsenal, AL 35809
		1	Commander US Army Missile Command ATTN: DRSMI-YDL Redstone Arsenal, AL 35809
1	Commander US Army Armament Materiel Readiness Command ATTN: DRSAR-LEP-L, Tech Lib Rock Island, IL 61299	1	Commander US Army Tank Automotive Research and Development Command ATTN: DRDTA-UL Warren, MI 48090
1	Director US Army ARRADCOM Benet Weapons Laboratory ATTN: DRDAR-LCB-TL Watervliet, NY 12189	3	Project Manager Cannon Artillery Weapons Systems ATTN: DRCPM-CAWS US Army Armament Research and Development Command Dover, NJ 07801
1	Commander US Army Aviation Research & Development Command ATTN: DRSAV-E P.O. Box 209 St. Louis, MO 61366	1	Director US Army TRADOC Systems Analysis Activity ATTN: ATAA-SL, Tech Lib White Sands Missile Range, NM 88002
1	Director US Army Air Mobility Research & Development Laboratory Ames Research Center Moffett Field, CA 94035	1	Sandia Laboratories ATTN: H. Vaughn Albuquerque, NM 87115

No. of Copies	Organization
1	Director National Aeronautics & Space Administration Goddard Space Flight Center ATTN: Guidance & Control Br Greenbelt, MD 20771
1	Aerospace Corporation ATTN: Walter F. Reddall 2350 East El Segundo Blvd. P.O. Box 92957 Los Angeles, CA 90009
2	Calspan Corporation ATTN: G. Homicz W. Rae P.O. Box 235 Buffalo, NY 14221

Aberdeen Proving Ground

Dir, USAMSAA
ATTN: DRXSY-D
DRXSY-MP, H. Cohen

Cdr, USATECOM
ATTN: DRSTE-TO-F

PM SMOKE, DRCPM-SMK, Bldg. 324
(2 cys)

Dir, USACSL, EA
ATTN: DRDAR-CLN-S, W. Dee
DRDAR-CLN-SM, J. McKivrigan
Bldg. E3330
DRDAR-CLB-PA, M. Miller
Bldg. E3516

USER EVALUATION OF REPORT

Please take a few minutes to answer the questions below; tear out this sheet, fold as indicated, staple or tape closed, and place in the mail. Your comments will provide us with information for improving future reports.

1. BRL Report Number ______________________

2. Does this report satisfy a need? (Comment on purpose, related project, or other area of interest for which report will be used.)

____

____

____

3. How, specifically, is the report being used? (Information source, design data or procedure, management procedure, source of ideas, etc.) ______________________

____

____

4. Has the information in this report led to any quantitative savings as far as man-hours/contract dollars saved, operating costs avoided, efficiencies achieved, etc.? If so, please elaborate.

____

____

5. General Comments (Indicate what you think should be changed to make this report and future reports of this type more responsive to your needs, more usable, improve readability, etc.) ______________________

____

____

____

6. If you would like to be contacted by the personnel who prepared this report to raise specific questions or discuss the topic, please fill in the following information.

Name: ______________________

Telephone Number: ______________________

Organization Address: ______________________

____

____

— — — — — — — — — — FOLD HERE — — — — — — — — — — —

Director
US Army Ballistic Research Laboratory
Aberdeen Proving Ground, MD 21005

NO POSTAGE
NECESSARY
IF MAILED
IN THE
UNITED STATES

OFFICIAL BUSINESS

PENALTY FOR PRIVATE USE, $300

BUSINESS REPLY MAIL

FIRST CLASS PERMIT NO 12062 WASHINGTON, DC

POSTAGE WILL BE PAID BY DEPARTMENT OF THE ARMY

Director
US Army Ballistic Research Laboratory
ATTN: DRDAR-TSB
Aberdeen Proving Ground, MD 21005

— — — — — — — — — — FOLD HERE — — — — — — — — — — —